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Applying computational semantics to the real-time communication of skill knowledge

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Title

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Abstract

Global skill shortages are reported in many occupations. Existing strategies for addressing skill shortages are not successful and, as a result, skill shortages are an intractable problem. A new strategy, real-time communication of skill knowledge without human instructors, has the potential to bring about radical reductions in skill shortages. The goal of the study reported in this VTT Working Paper was to determine how skill knowledge could be communicated in real-time without reliance on access to a person with relevant existing skill knowledge. In particular, the communication of manual skills. The research involved literature review and field study. Literature review encompassed studies concerned with skill knowledge, communication media, and computational semantics. Field study involved interviews with industry practitioners seeking to address skill shortages and computational semantics scientists. The study revealed that many of the technologies and methods required for the real-time communication of skill knowledge without human instructors are already available. Further, the study revealed that computational semantics is essential to the successful application and integration of these technologies and methods.

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Preface

The research reported in this VTT Working Paper was funded by Tekes (Finnish Funding Agency for Technology and Innovation) and VTT (Technical Research Centre of Finland). The research was an addition to the Finnish research and development project with the short name, SPECIAL. This project short name is a summary for the full project name: Rapid Economic Production of Special Products. Special products are created whenever individuals have authority over design and/or production. Larger special products, such as ships and oil refineries, are created through processes which are often referred to as engineer-to-order. Smaller special products, such as furniture and clothes, are created through processes which are often referred to as bespoke. All of the product types shown on the front cover of this VTT Working Paper can be referred to as special products. Much of the design and production of Special products cannot be automated. This is because the form, finish and configuration of components are uncertain from one order to the next. As a result, it is neither technically feasible nor economically viable to invest in product-specific automated tooling, equipment and systems. As a consequence, the creation of special products can be highly dependent on the availability of people with manual skills. The SPECIAL project involves a variety of Finnish companies. Like many others throughout the World, all of these companies have to try to overcome skill shortages when seeking to maintain and improve their performance.

Finland is a leader in the development of advanced information and communications technologies (aICTs). These enable improved information and/or communication by surpassing, in one or more characteristics, combinations of existing information and communication technologies. As shown in Figure 1 below, aICTs, such as Augmented Reality, have potential to enable the real-time communication of skill knowledge to people who do not have relevant existing skills.

Figure 1. Examples of Augmented Reality devices. (Source: see p. 82.)

However, skill knowledge is typically communicated through one-to-one face-to-face human interaction between a person with relevant existing skills (e.g. a craftsperson) and a person without relevant existing skills (e.g. an apprentice). Such interactions can include physical demonstrations, audio feedback, visual feedback and very flexible dialogues. For example, the skill of how to knock a nail into a piece of wood could first involve a physical demonstration by the person with skill knowledge. Next, the person without skill knowledge would make an attempt. If the sound of the hammer hitting the nail did not ring true, that would be audio feedback. If the nail were to start to bend, that would be visual feedback. Extemporaneous dialogue might follow in which the person with skill knowledge would take hold of the person without skill knowledge in order to guide her/his physical movement. In other words, the skilled person in this example is both the repository of knowledge and the multimodal communicator of that knowledge.

The goal of research reported in this VTT Working Paper was to determine how one-to-one human communication of skill knowledge held by human memory could be equalled, or surpassed, by aICT communication of skill knowledge held within aICT repositories. Obtaining input from scientists with expertise in computational semantics and pragmatics was essential to the research. This is because computational semantics and pragmatics are concerned with the computation of meaning during the exchange, sharing and development of knowledge between people and computers. Accordingly, the research reported in the fourth section of this VTT Working Paper was carried out by its lead author during a stay of three months at Stanford University's Computational Semantics Laboratory (SemLab). The co-authors of this VTT Working Paper were all based at SemLab during that time and all contributed to the fourth section of this VTT Working Paper. In addition, the lead author undertook discussions with other experts across Stanford University's Human Sciences and Technology Advanced Research Institute (H-Star). Any errors in any section of this Working Paper are the sole responsibility of the lead author.

Stephen Fox

Espoo, January 2008

Contents

List of Figures

List of Tables

1. Introduction

In this section, the background of the study is described. Further, the research goal and the research method are outlined. Subsequently, the overall structure of the working paper is set out.

1.1 Background

Skill is an ability to perform a task at a required level of competence. As summarized in Table 1 below, skills can be described under the following four headings: inherent, basic, general, specific.

Table 1. Types of skill.

Skill Type	Examples
Inherent	Psychomotor, conceptual
Basic	Literacy, numeracy
General	Problem-solving, teamwork
Specific	Material handling, tool selection

Skills which are inherent among human beings include: psychomotor skills as demonstrated through e.g. manual dexterity; perceptual skills as demonstrated through e.g. sensing; conceptual skills as demonstrated through inferring; discretionary skills as demonstrated through decision making. Basic skills, such as literacy and numeracy, are taught during basic education and provide a useful foundation for all occupations. General skills, such as problem-solving and team-working, are those which can contribute to performance within all occupations. Specific skills, such material handling and tool selection, are those which are particular to a specific occupation. As illustrated in Figure 2, inherent skills, basic skills and general skills can all contribute to the successful acquisition and execution of specific skills.

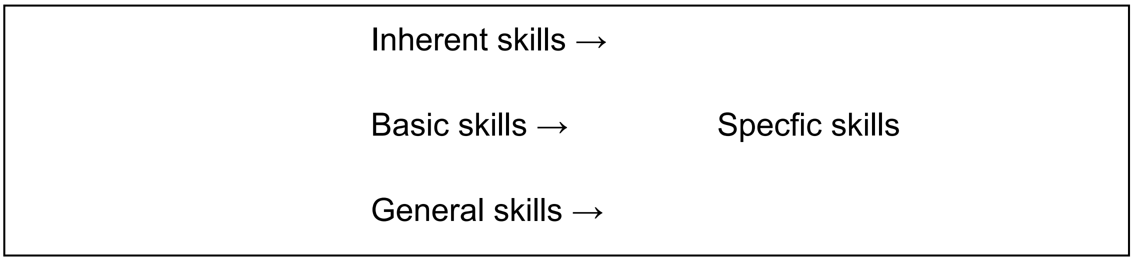


Figure 2. Specific skills.

The research reported in this VTT Working Paper was concerned with the communication of specific skills used during manual work. In particular, the communication of specific manual skills to people who lack basic skills. This is because functional illiteracy (in reading, writing and mathematics) is a widespread barrier to the communication of skill. Firstly, because functional illiteracy is prevalent within many countries including industrialized nations such as Britain and the USA (BBC, 2000). Secondly, because many people who are literate in their home country can find themselves to be functionally illiterate when they migrate to other countries in which other languages are used. A summary of the research focus is presented in Figure 3 below.

Research Focus

Communication of

specific skill knowledge required during manual work

to people without basic skills

Figure 3. Research focus.

Global skill shortages exist in many occupations. Global skill shortages have been reported in many occupations (Cohen and Zaidi, 2002). In 2007, the Australian government, for example, reported a lack of people with the necessary skills to be employed as: automotive electricians, bakers, binder and finishers, bricklayers, business equipment technicians, butchers, cabinetmakers, carpenters, chefs, cooks, dentists, electricians, electrotechnology assemblers, engineering tradespersons – fabrication, floor finisher and coverers, furniture polishers, glass and glazing tradespersons, hairdressers, heavy vehicle motor mechanics, joiners, lift electricians, light vehicle motor mechanics, painter and decorators, panel beaters, pastrycooks, plasterers, plumbers, printing machinists, roofers, shipwrights, tilers – wall and floor, upholsterers, vehicle body builders, vehicle painters, vehicle trimmers, wood machinists (DEST, 2007a). All of these occupations involve manual work. Similarly, New Zealand's Department of Labour maintains an Immediate Skill Shortage List (ISSL) that filled twenty-six pages in 2007. The ISSL included agricultural machinery operators, arborists, autoglaziers, coachbuilders, crane operators, die cutter operators, drain layers, fibreglass tradesperson, marine laminators, plastics die setters, scaffolders, sheet metal workers, telecommunications engineers. New Zealand's Department of Labour also maintains a list of what it terms, absolute skill shortages. In 2007, this list included: electricians, automotive electricians, diesel mechanic, motor mechanic, auto air conditioning technicians, fitter & turners, fitter welders, cabinet makers, boatbuilders, carpenter/joiners, plumbers, line mechanics. Again, all of these occupations involve manual work (New Zealand Department of Labour, 2007).

Existing strategies for addressing skill shortages are not successful. The causes of skill shortages have been investigated for decades (e.g. Abraham and Katz, 1986; Borthwick et al., 2000; Brunello, 1991; Davis and Haltiwanger, 1992; Hart and Shipman, 1991; Haskel and Martin, 1993; Lilien, 1982; Loungani et al., 1990). These include: growth of new industries that require new skills; technological changes in an existing industry resulting in new skill requirements; demographic changes resulting in more retirements than recruits; insufficient geographic mobility of skilled workers; reduced attractiveness of established industries to potential recruits; insufficient investments in skills training due to economic fluctuations; the long length of time required for the acquisition of skills. Strategies for addressing with skill shortages have been implemented for decades. These include: improving the image of industries; developing better forecasting and recruitment practices; limiting early retirement and facilitating re-entry of older workers to the job market; flexible training programmes to enable the life-long learning of skills. Such strategies are implemented through multinational, national, regional, local and/or company programmes (e.g. DEST, 2007b; Stenberg, 2006). Nonetheless, global skill shortages persist despite understanding of causes and implementation of strategies. For example, a 2007 survey of Chief Executive Officers throughout Asia revealed skill shortages to be the number one concern among business leaders in China, the second biggest concern in Japan and the fourth biggest concern in India (The Economist, 2007a). Further, skill shortages are reported in small countries as well as big countries. For example, it was reported in 2007 that skill shortages were are major concern for companies in the Gulf States (GulfTalent.Com, 2007).

Currently, global skill shortages are an intractable problem. Skill shortages in different parts of the World may occasionally be highlighted by their negative affect on high profile projects, such as the building of stadiums for the 2010 soccer World Cup in South Africa (The Economist, 2007b). However, skill shortages are a persistent and intractable problem, not an occasional problem, throughout the World. Indeed, it is important to note that countries such as Australia, Britain, Canada and New Zealand continue to suffer from skill shortages even after decades of implementing strategies to address skill shortages (BBC, 2006; Beauchesne, 2006). Further, such countries continue to suffer from skill shortages even after decades of receiving skilled immigrants from around the World. Moreover, the migration of skilled people causes skill shortages within their countries of origin. For example, a 2007 survey revealed that out-migration to countries in Western and Northern Europe had contributed to skill shortages in central European countries (World Bank, 2007). Nonetheless, skill shortages continue to be reported in countries such as Germany and Finland (Deutsche Welle, 2007; OECD, 2008). Similar, 78 percent of Mexican employers participating in a 2007 survey said they faced a shortage of skilled workers (Beauchesne, 2006). Meanwhile, skill shortages persist in USA despite the ongoing influx of skilled workers from Mexico (Deloitte and Touche, 2007).

Skill shortages will remain intractable until the time needed to acquire skill knowledge is radically reduced. This is because the causes of skill shortages will continue to be extremely difficult to address until the time needed to acquire specific skills is radically reduced. Consider, for example, how global real-time communication of skill knowledge would affect the following three major causes of skill shortages. Firstly, global real-time communication of skill knowledge could enable rapid training for new skills required by new industries. Secondly, global real-time communication of skill knowledge could enable rapid training of new skill requirements arising from technological changes in existing industries. Thirdly, global real-time communication of skill knowledge could enable rapid training to address skill shortages arising from insufficient prior training investments due to economic fluctuations. As summarized in the text box, the term, real-time, means to occur immediately. Existing examples of real-time communication are video conferencing, credit card verification, and real-time games. During video conferencing, the processing of information returns a result so rapidly that the interaction appears to be instantaneous. During credit card verification, both card validity and available credit can be checked immediately. During real-time games, players can make moves whenever they like. By contrast, in turn-based games like chess, players must wait for other players to make their moves. A summary of this description is provided in Figure 4 below.

Real-time Communication

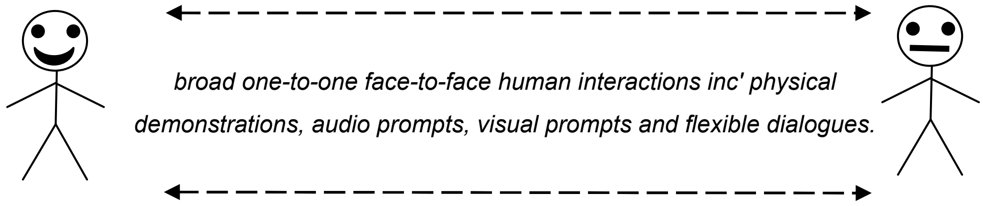
Interaction appears to be instantaneous

e.g. video conference meeting, credit card verification

Figure 4. Real-time communication.

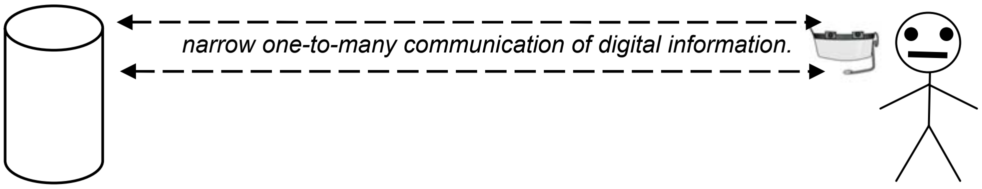
Current methods of communicating skill knowledge are too slow. Today, knowledge of specific skills is often communicated through one-to-one interaction between a person with specific skill knowledge (e.g. a craftsperson) and a person without that specific skill knowledge (e.g. an apprentice). This approach has a number of serious limitations. First, there can be a shortage of people with specific skill knowledge available to communicate what is needed. This can mean that there are no people with specific skill knowledge available at all; or that the ratio of skilled to unskilled is too low to enable the communication of skill knowledge when it is needed. Also, the scope and depth of different people's specific skill knowledge can vary and may not be an ideal match with many specific skill requirements in many situations. Further, some people with a high degree of specific skill knowledge may not be particularly good at communicating what they know to anybody, or at least not particularly good at communicating to slow learners, and/or people with another first language, and/or people who lack basic skills. All together these factors mean that the communication of specific skill knowledge, which is most appropriate to the task requirement and to the person, may often not be available when it is needed. In summary, the communication of skill knowledge is currently NOT available on-demand in real-time in response to the requirements of a particular task to be executed by a person with her/his own individual mix of inherent, basic and general skills. Rather, the communication of skill knowledge is much less focused and much less immediate. This is because the current repositories of skill knowledge are people (e.g. craftspersons) and because the current medium for the communication of skill knowledge is people (e.g. craftspersons).

Can the time required to communicate skill knowledge be reduced? There are two complementary approaches that could lead to radical reductions in the time needed to communicate specific skills. The first is to design products and processes so that the specific skills required by them are much easier to communication to more people more quickly. The second is to formulate the communication of specific skill knowledge so it can be understood by more people more quickly. This second approach involves changing the primary repository of skill information from being a person (e.g. a craftsperson) to being digital information system (e.g. a knowledge-base). It also involves changing the primary medium for the communication of skill information from being a person (e.g. a craftsperson) to being an electronic medium (e.g. an augmented reality headset). Accordingly, types of human messages that have been used to communicate skill knowledge may often need to be reformulated. This may be particularly challenging for the skills involved in manual work. This is because such skills involve tacit procedural knowledge. Procedural knowledge can be contrasted to declarative knowledge (Snow and Lohman, 1989). Declarative knowledge can be said to be informational in nature. By contrast, procedural knowledge involves the “how-to” knowledge that is essential to the execution of skills. Tacit knowledge is difficult, and sometime impossible, to verbalize (Sternberg, 1988). By contrast, explicit knowledge is operationally defined as information that can be verbally described. Further, manual work often involves psychomotor skills. These are skills that require the integration of mental and muscular activities. For example, complex sequences of actions that require perceptual information (e.g. input from the eyes) and control of the muscles. Psychomotor skills are often communicated through repeated physical demonstrations. Further, the communication of psychomotor skills may include instructors taking hold of learners to help them align their own physical movements with the optimum physical movements for the execution of a task. Learning often involves observation, trial and error practice. Further, competence can be difficult to measure (e.g. Wang et al., 2007). The fundamental changes required are illustrated in Figure 5.



Traditional communication of specific skill knowledge

Person with specific skill knowledge is:
primary repository of knowledge, and
primary medium of communicating knowledge



Future communication of specific skill knowledge?

Digital information systems are primary repository of knowledge
aICTs, such as AR headsets are primary medium of communicating knowledge

Figure 5. Changing communication.

The real-time communication of specific psychomotor skills to people without relevant existing skills and without basic skills is a profound challenge. Nonetheless, there are resources which can be drawn upon to enable this. Many of these resources can be discussed under three headings: theories of skill knowledge; innovations in communication; and advances in computational semantics. In particular, computational semantics is concerned with the computation of meaning. The computation of meaning is essential to the exchange, sharing and development of knowledge between computers and people. Accordingly, computational semantics is essential to real-time communication of specific pyschomotor skills. However, in order to be successful, computational semantics applications will need to be informed by, and compatible with, theories of skill knowledge and innovations in communication.

1.2 Research goal

The goal of the study reported in this VTT working paper was to determine how specific skill knowledge could be communicated in real-time to people who do not have relevant existing skill knowledge (e.g. an apprentice) – without reliance on access to a person with relevant existing skill knowledge (e.g. a craftsperson). In particular, the communication of specific psychomotor skills required during manual work. Further, the research goal was determine how specific skill knowledge could be communicated in real-time to people without relevant existing specific skill knowledge and who also do not have basic skills such as literacy and numeracy.

1.3 Research method

The research involved literature review and field study. Literature review encompassed studies concerned with skill knowledge, communication media, and computational semantics. Field study included interviews with industry practitioners seeking to address skill shortages and interviews with computational semantics scientists.

1.4 Research reporting

The remainder of this working paper comprises a further five sections. In the next section, findings relating to skill knowledge are reported. In section three, an overview is provided of different types of innovations which could be used to facilitate the real-time communication of skill knowledge. In section four, advances in computational semantics are discussed. In section 5, strategies for achieving the real-time communication of specific pyschomotor skills are presented. In the final section, conclusions from the research and directions for future research are presented.

2. Theories of Skill Knowledge

In this section, the nature of psychomotor skills is discussed. Then, taxonomies of psychomotor skills are described. Next, an overview of important topics in the learning and instruction of psychomotor skills is provided. In the concluding subsection, the principal findings of this part of the research are listed.

2.1 Psychomotor skills

Psychomotor skills can be fine – gross; open – closed; discrete – serial – continuous (Gilchrist and Gruber, 1984). The environments in which psychomotor skills are performed may be fixed, stable or moving. The nature of the performance environment determines the nature of the successful pattern of movement that will be developed as a result of practice of a particular motor skill (Gentile, 1977). Fine motor skills involve neuromuscular coordination that are usually precision orientated and involve hand-eye coordination. Some examples are holding a panel pin against a glazing bead while hitting it with a hammer. A gross motor skill involves contractions and usage of the large muscle of the body and the whole body is usually in movement, for example, when swinging a sledge hammer. Examples are shown in Figure 6 below.

Figure 6. Fine and gross psychomotor skills. (Source: see p. 82.)

Open skills are those in which the environment is unstable, changeable and moving. The objective in motor skills is to develop a repertoire of movements within a particular class of movement to enable the performer to respond to the changing environments. Closed skills are those in which the performance environment is stable, fixed, repetitive and unchanging between movement selection, initiation, and completion. In closed skills, the goal is to be able to repeat a specific skill as consistently as possible, to habituate skill performance. A continuous task involves a series of adjustments of flowing movements usually without an acknowledged termination point in time or specified movement. Discrete tasks contain one unit or a series of separate units with a fixed beginning or end (Perencevich et al., 2005).

Innate abilities underlie the acquisition of all psychomotor skills. Abilities can be considered to be general and enduring. Psychomotor abilities include balance, limb speed, manual dexterity, muscle power, precision of movement, and spatial perception. Psychomotor ability is often referred to in terms of fine functioning (with e.g. fingers, hands, arms) and gross functioning (with e.g. legs, torso). Factors such as muscle power, persistent control, kinasesthetic integration and bimanual dexterity are considered within motor functioning (McCarron, 1982). Muscle power includes hand and leg strength. Persistent control factor incorporates perceptual skills with the regulation of hand-arm movements. Kinaesthetic integration factor involves the control of balance and the orientation of the body in space. Bimanual dexterity is a measure of precise co-ordination of both hands. Spatial perception is a factor related to psychomotor ability. This is the ability to the relations of objects in space, to judge their shapes and sizes, to manipulate them mentally, and to vizualize the effects of putting them together or turning them around (Super, 1949). Spatial perception can include factors such as spatial relations and orientation, visualization and kinaesthetic imagery. Psychomotor performance is affected by endurance and emotional factors.

Psychomotor ability varies from individual to individual (Fleishman and Bartlett, 1969). In infancy psychomotor activity is random and uncontrollable. Only gradually does intent and performance come together. Over time, physical actions can become routinized and may be subject to deliberate, controlled modification. Behaviorists have studied physical training carefully. A physical action may be learned by observing it, mimicking it, perhaps with support from coaching, visible examples, physical or verbal guidance of actions, as so on. If it is a complex action, we can learn it by breaking it into steps and performing each step, then by linking the steps into sequences, and by rehearsing the sequence until it becomes automatic. We eventually gain the ability to modify and adapt an action creatively (Carson, 2004). Psychomotor ability is defined as the relatively innate potential to acquire psychomotor skills after practice (Schmidt, 1982). Psychomotor ability is present at birth and relatively unchanging over life. In general, increased amounts of practice can compensate for lesser psychomotor ability and lead to desired or necessary levels of psychomotor skill proficiency. However, if psychomotor ability is very low, the acquisition of high psychomotor skill could be almost impossible (Kaufman et al., 1987).

2.2 Taxonomies of psychomotor skills

Overview. Taxonomies have been formulated to assist in the classification of learning behaviors and the identification of different levels of learning. Taxonomies can be used to guide the development of higher education curricula and training programmes. In particular, taxonomies can provide a better understanding of both the commonalities and differences among psychomotor skills across several dimensions, and a recognition of requirements either similar or unique, involved in performance (Perencevich et al., 2005). Taxonomies of psychomotor skills tend to describe a progression from observation to mastery of physical skills. Perhaps the earliest, and best know, taxonomy of learning is Bloom's Taxonomy. This taxonomy is the work of a group of educational psychologists, led by Benjamin Bloom who developed a classification of levels of intellectual behavior important in learning. This became a taxonomy including three overlapping domains; the cognitive, affective, and psychomotor (Bloom et al., 1956; Anderson and Krathwohl, 2001). An important premise of Bloom's taxonomy is that each category (or 'level') must be mastered before progressing to the next. As such the categories within each domain are levels of learning development, and these levels increase in difficulty. The significance of the work of Bloom and colleagues on taxonomies was that it was the first attempt to classify learning behaviors and provide concrete measures for identifying different levels of learning. Cognitive learning consisted of 6 levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. The Affective domain (e.g., Krathwhol et al., 1964) consisted of behaviors corresponding to attitudes of: receiving, responding, valuing, organizing values, and integrating values into a total philosophy and acting consistently in accordance with that philosophy. This domain relates to emotions, attitudes, appreciations, and values, such as enjoying, conserving, respecting, and supporting. Although not part of the original work by Bloom, others went on to complete the definition of psychomotor taxonomies. Examples psychomotor taxonomies are described in the following paragraphs.

Dave's taxonomy. R.H. Dave was a student of Benjamin Bloom when he was developing his taxonomy in the late 1960's. He proposed five learning levels: Imitation (attempt, copy, duplicate, imitate, mimic, practice, repeat, reproduce, try); Manipulation (complete, follow, play, perform, produce); Precision (achieve automatically, excel expertly, perform masterfully); Articulation (adapt, alter, customize, orginate); Naturalization (naturally, perfectly). Imitation involves patterning behaviour after someone else by observing a skill and seeking to repeat it. Manipulation involves performing the skill by following general instructions rather than observations. Precision involves independent performance of a skill at an expert level. Articulation involves modifying the skill to fit new situations, and combining more than one skill in sequence with harmony and consistency. Naturalization involves completion of one or more skills with ease and making the skill automatic with limited physical or mental exertion (Dave, 1970). In Table 2 below, Dave's taxonomy of psychomotor outcomes is placed alongside Bloom's taxonomy of cognitive and affective outcomes. The "highest levels" are written at the top of each column.

Table 2. Cognitive, affective and psychomotor taxonomies.

Cognitive categories	Affective categories	Psychomotor categories
Evaluation	Integrating values	Naturalization
Synthesis	Organizing values	Articulation
Analysis	Valuing	Precision
Application	Responding	Manipulation
Comprehension	Receiving	Imitation
Knowledge		

Simpson's taxonomy. Elizabeth Simpson's interpretation of the Psychomotor domain differs from Dave's chiefly because it contains extra two levels prior to the initial imitation or copy stage (Simpson, 1966; 1972). In total, she proposed seven levels: Perception (becoming aware of simulation and the need for action); Set (preparing for action); Guided Responses (responding with assistance from a teacher or coach); Mechanism (responding habitually); Complex Response (resolving uncertainty and performing difficult tasks automatically; Adaptation (altering responses to fit new situations; Origination (creating new acts or expressions). Arguably for certain situations, Simpson's first two levels, 'Perception' and 'Set' are assumed or incorporated within Dave's first 'Imitation' level. However, for young children, or for adults learning entirely new and challenging physical skills (which may require some additional attention to awareness and perception, and mental preparation), or for anyone learning skills which involve expression of feeling and emotion, then Simpson's taxonomy could be more useful because it more specifically address these issues. Simpson's version is particularly useful if taking adults out of their comfort zones, because it addresses sensory, perception (and by implication attitudinal) and preparation issues. For example anything fearsome or threatening, like emergency routines, conflict situations, tough physical tasks or conditions (Chapman, 2006). In Table 3 below, Dave's taxonomy is placed alongside Harrow's taxonomy and Simpson's taxonomy.

Table 3. Psychomotor taxonomies.

Dave's taxonomy	**Harrow's taxonomy**	**Simpson's taxonomy**
Naturalization	Non-discursive communication	Origination
Articulation	Skilled movements	Adaptation
Precision	Physical abilities	Complex overt response
Manipulation	Perceptual awareness	Mechanism
Imitation	Basic fundament movements	Guided response
	Reflex movements	Set
		Perception

Harrow's taxonomy. Anita Harrow (1972) proposed six learning levels: Reflex (objectives not usually written at this "low" level); Fundamental movements – applicable mostly to young children (crawl, run, jump, reach, change direction); Perceptual abilities (catch, write, balance, distinguish, manipulate); Physical abilities (stop, increase, move quickly, change, react); Skilled movements (play, hit, swim, dive, use); and Non-discursive communication (express, create, mime, design, interpret). Harrow's taxonomy is organized according to the degree of co-ordination including involuntary responses as well as learned capabilities. Simple reflexes begin at the lowest level of the taxonomy, while complex neuromuscular co-ordination make up the highest levels (Seels and Glasgow, 1990). Reflex movements are actions elicited without learning in response to some stimuli. Examples include: flexion, extension, stretch, postural adjustments. Fundamental movements are inherent movement patterns which are formed by combining reflex movements and are the basis for complex skilled movements. Perceptual abilities enable adjustments to the environment based on interpretations of various stimuli. This involves visual, auditory, kinaesthetic, or tactile discrimination, and can include cognitive, as well as psychomotor, behaviour. Physical abilities require endurance, strength, vigor, and agility. Skilled movements are the result of the acquisition of a degree of efficiency when performing a simple task. Non-discursive communication ranges from facial expressions through to sophisticated choreographics. Harrow's taxonomy is concerned with the teaching of physical education and it has been argued that her taxonomy does not adapt easily to the full range of psychomotor skills (Maclay, 1969; Maclay, 1974). However, it has been argued that Harrow's taxonomy is particularly useful if you are developing skills which are intended ultimately to express, convey and/or influence feelings, because its final level specifically addresses the translation of bodily activities (movement, communication, body language, etc) into conveying feelings and emotion, including the effect on others. For example, public speaking, training itself, and high-level presentation skills (Chapman, 2006).

Other general taxonomies for psychomotor skills. Several other taxonomies in the psychomotor domain have been developed. Five taxonomies that do not have a specific industry or trade focus are outlined here. Like the taxonomies described about, these have a general scope of application. Dawson (1998) has sought to develop a psychomotor extension to Bloom's taxonomy comprising six levels: Observation, Trial, Repetition, Refinement, Consolidation, Mastery. Annette Freak and colleagues (2006) have proposed a six level hierarchy comprising: Masquerading, Imitating, Patterning, Mastering, Applying, Improvising. Krathwohl, one of the original contributors to Bloom's taxonomy, proposed a hierarchical taxonomy comprising five levels: Nonlocomotor movements; Readiness; Movement skill development; Movement pattern development; Adapting and originating movement patterns. Maclay (1969) proposed a taxonomy comprising six levels: Perception; Readiness, Guided response, Mechanism, Complex response with guidance, Complex response without guidance. Kathleen Perencevich and colleagues (2005) have proposed a four level taxonomy comprising: Acquisition, Automaticity, Transfer: near term, Transfer, far term. Among these four taxonomies, Dawson's has the benefit of using only self-explanatory everyday terms.). In Table 4 below, these five taxonomies are placed alongside each other.

Table 4. Psychomotor taxonomies.

Dawson	**Freak**	**Krathwohl**	**Maclay**	**Perencevich**
Mastery	Improvising	Adapting	Complex response without guidance	Transfer – far term
Consolidation	Applying	Patterning	Complex response with guidance	Transfer – near term
Refinement	Mastering	Skill	Mechanism	Automaticity
Repetition	Patterning	Readiness	Guided response	Acquisition
Trial	Imitating	Movement	Perception	
Observation	Masquerading		Readiness	

Examples of psychomotor skill taxonomies for specific skills. The development of taxonomies is closed related to the use of instructional objectives and the systematic design of instructional programs. Hence, in addition to taxonomies that are intended for general application, taxonomies have been developed for specific skills. Two such taxonomies are outlined here. Kaufman et al. (1987) formulated a taxonomy for surgical psychomotor skills. They broke down the skills required for surgical procedures into a number of obvious categories, including dissection, retraction and repair. These categories were further divided into subcategories, some related to the use of specific surgical instruments. In addition, they related psychomotor abilities and level of skill needed to categories. Ferris and Aziz (2005) proposed a psychomotor skills taxonomy for engineering students comprising seven levels: Recognition of tools and materials; handling of tools and materials; basic operation of tools; competent operation of tools; expert operation of tools; planning of work operations; evaluation of outputs and planning means of improvement.

2.3 Learning of psychomotor skills

Models of learning. Psychological factors and physical factors affect learning. Some necessary psychological factors include motivation, attention, feedback and retention. Vision, hearing, fatigue and kinaesthesia (the perception of body position and movement and muscular tensions) are examples of physical factors that affect acquisition of psychomotor skills. The general process of psychomotor skill instruction and learning can be said to have three levels: beginning, intermediate, advanced. Scholars have identified the characteristics of such levels. Further, scholars have argued that they generalize well across specific educational situations.

For example, Fitts and Posner (1967) found that the acquisition of psychomotor skills occurs in three distinct stages – cognitive, associative, autonomous. During the *cognitive stage*, the psychomotor skill learner much become cognitively aware of the demands of the task which s/he is about to learn. It has been suggested that a learner cannot adequately acquire a psychomotor skill until these cognitive questions have been answered. The *associative stage* is a stage of practice and repetition. Through trial and error learning, the student begins to approximate the goals of the practice. After practice and experience with the skill, the learner may move to the *autonomous* stage in which s/he is able to perform the task with little or no cognitive intervention. Moreover, the continued use of cognitive processes during the performance of psychomotor skill greatly slows and inhibits the performance of that skill.

Adler (1981) argues that there are three stages of psychomotor development: concept, adaptation, automation. In the concept stage, learners first become aware of what will be needed to perform the basics aspects of the whole task. Initial concept formation relies heavily on visual information and active demonstrations of performance. Verbal descriptions seem to be least efficacious in communicating the demands of what is essentially physical information. The second aspect of concept formation is actual accomplishment of the entire task. Concept formation is not complete until the learner knows what it is like to perform the skill. Reliance on vision is still the most efficient strategy. However, limited verbal assistance has value in this aspect as well. The concept stage is completed and the adaptation stage begins when the learner is capable of performing the entire skill. In the adaptation stage, performance is adjusted to bring it closer to some form of accuracy. The training process includes shaping; the learner is brought successfully closer to the ideal performance. Adler (1981) stresses the differences between open and closed skills in the adaptation stage. Regardless of the type of skill, the instructor can assist by focusing the learner's attention on aspects of the skill that require correction or adaptation. The automation stage is reached when the learner can perform without conscious attention to the movement. The attention of the learner is diverted away from the movement and the changes in performance are noted.

Romiszowski (1999) argues that there are five stages of learning psychomotor skills. Stage 1 involves acquiring knowledge of what should be done, to what purpose, in what sequence, and by what means. Stage 2 involves the execution of the actions in a step-by-step manner, for each of the steps of the operation. Stage 3 involves transfer of control from the eyes to the other senses or to kinaesthetic control through muscular coordination. Stage 4 involves the automatization of the skill. Stage 5 involves generalization of the skill to a continually greater range of application situations. Perencevich, Seidel and Kett (2005) argue that Romiszowski's model suggests three basic steps in the overall instructional process: Imparting knowledge content; Imparting the basic skills; Developing proficiency. In Table 5 below, Fitt and Posner's model is placed alongside Adler's model and Romiszowski's model.

Table 5. Three models.

Fitts and Posner's	Adler's	Romiszowski's
Autonomous	Automation	Proficiency
Associative	Adaptation	Basic skills
Cognitive	Concept	Knowledge

Task analysis is required to determine the psychomotor skills necessary. It has been argued that effective and efficient acquisition and performance of movement skills depends upon learners' ability to focus their attention on selected aspects of the movement task (Shasby, 1984). Accordingly, the skills required for different tasks can be broken down into a number of categories. These categories can be further divided into subcategories and related to the use of specific tools. Within each category, there may be a need, to a greater or lesser extent, for the different types of psychomotor ability. A grading system for the level of skill needed in each category can be introduced. Also, each task can be given an overall difficulty rating. This could go beyond consideration of psychomotor skill requirement to include, for example, task planning, task safety. The results of task analyses provide a tangible reference for instruction. Each analysis must be complete, presented in the proper amount of detail, with relationships among component skills and concepts clearly specified. It should identify when and under what circumstances each component will be performed. In short, the task analysis provides a blueprint of the things the learner must master if he is to reach the objectives that have been set. Thus, upon completion of the task analyses, a teaching sequence can be developed and the psychomotor subcomponents of a training programme can be most efficiently presented (Anderson and Faust, 1973). Three general approaches to task analysis were identified by Jonassen et al. (1989) as behavioural analysis, subject matter analysis, and information processing analysis. Behavioural analysis requires identifying specific behaviours needed to perform a complex task. Subject matter analysis involves breaking down a task into specific topics, concepts and principles. Information processing analysis involves identifying cognitive processes involved in a task (Perencevich et al., 2005).

Different types of practice can have different consequences. Practice can be physical and/or mental. Physical practice can encompass all of a task or part of a task. Parts of a task can be practiced sequentially until the whole task is being practiced (van Merrienboer et al., 2003). Mental practice is a cognitive strategy used to acquire, rehearse or enhance a physical skill. Mental practice can involve imagining the use of skills to perform tasks and/or inner speech to guide oneself through new or difficult tasks (Vygotsky 1978; 1997). Research suggests that mental practice can have a positive effect on performance (Driskell et al., 1994). However, research suggests the effectiveness of mental practice is moderated by the type of task, the retention interval between mental practice and performance, and the length of duration of the mental practice intervention (Driskell et al., 1994). Mass practice is practice with no, or very limited, amounts of rest between the practice sessions. By contrast, distributed practice includes periods of rest (Caple, 1996). Massing of practice leads to greater efficiency in the use of time. However, the build up of physiological fatigue and psychological fatigue in the learner can be detrimental to skill acquisition process (Godwin and Schmidt, 1971). The continued practice of a psychomotor skill after that skill has been mastered can be referred to as overlearning (Rohrer et al., 2005). The meaningfulness of a practice session also affects retention (Leavitt and Schlosberg, 1944). Individuals remember things that they consider meaningful, while they forget those things that they feel are irrelevant. Also, it is recognized that there is a significant interaction between the interest of the learner and the acquisition of psychomotor skills. Unmotivated learners may not acquire skill. Going through the motions of the practice session may not lead to the acquisition of skill. Rather, learners who are motivated and attend to the precise aspects of practice may be more likely to acquire skill. Motivation can be improved in learners by establishing the relationship between practice and the performance of skills that will be needed in their tasks. On the other hand, anxiety is detrimental; anxious learners do not readily acquire psychomotor skills

Visual demonstrations are able to convey large amounts of skill information (Perencevich et al., 2005). Visual demonstrations are considered to be powerful tools to convey large amounts of psychomotor skill-related information to learners in a short time. Fleishman and Rich (1963) argued that initial concept formation relies heavily on visual information. Verbal descriptions seem to be least effective in the communicating the demands of what are essentially physical information. Indeed, it could be argued that specific psychomotor skills are tacit knowledge. As stated in earlier, that is knowledge which is difficult, and sometime impossible, to verbalize (Sternberg, 1988). By contrast, explicit knowledge is operationally defined as information that can be verbally described. Romiszowski (1999) states visual demonstrations, not necessarily with verbal commentaries, can be effective in facilitating learning. However, it has been argued that verbal mediation should be used to direct attention to the task at hand (Shasby, 1984). Nonetheless, visual demonstrations have long been acknowledged as one of the most powerful means of transmitting patterns of thought and behaviour (Bandura, 1986). With regard to mental practice it has been argued that visual imagery (i.e. images stimulated in the "mind's eye") is better for tasks that emphasize form while kinaesthetic imagery (i.e. the feel of the movement stimulated in the "mind's eye") is better for those tasks that emphasize timing for minute coordination of both hands (Féry, 2003). Mahoney and Avener (1977) distinguished between internal visual imagery and external visual imagery. In external imagery, people view themselves from the perspective of an external observer. By contrast, internal imagery requires an approximation of the real phenomenology such that the person actually imagines being inside her/his own body and experiencing those sensations that might be expected in the actual situation. There is some evidence that (Callow and Hardy, 2004) that both internal visual imagery and external visual imagery can be performed in conjunction with kinaesthetic imagery.

Augmented feedback is essential in learning psychomotor skills. It has been argued that augmented feedback is essential to the development of psychomoter skills (Magill, 2004; Schmidt and Lee, 2005). Augmented feedback can comprise knowledge of results and knowledge of performance. Knowledge of results (KR) is terminal feedback (visual, auditory, tactile evaluation information) provided to the learner after the completion of the task relative to the goal of the task. This can include spatial deviation from a target or temporal deviation from a goal movement time. Knowledge of performance (KP) refers to the nature of movement, such as kinematic information about the movement pattern produced. Knowledge of results can be provided in two ways: intrinsic or augmented. Intrinsic knowledge of results is available when tasks that have knowledge of results "built in to them". For example, if a nail is bent over when the psychomotor task is to knock a nail straight into a piece of wood. By contrast, augmented knowledge of results is evaluation information provided after the completion of a task from some source outside the task. Without augmented feedback, learners only gain an impression of how well or how poorly they performed task through their proprioception. This term comes from Latin *proprius*, meaning "one's own" and perception, and is the sense of the relative position of neighbouring parts of the body. Unlike the six exteroceptive senses (sight, taste, smell, touch, hearing, and balance) by which people perceive the outside world, and interoceptive senses, by which we perceive the pain and the stretching of internal organs, proprioception is a third distinct sensory modality that provides feedback solely on the status of the body internally. It is the sense that indicates whether the body is moving with required effort, as well as where the various parts of the body are located in relation to each other. It has been argued that without augmented feedback, learners will rely on their proprioception, and they will learn only to be consistently wrong – without realizing that they are wrong (Kaufman et al., 1987). A summary of augmented feedback terminology is provided in Table 6.

Table 6. Augmented feedback terminology.

Term	Description
Augmented feedback	Knowledge of performance and knowledge of results provided to learners by means other than their own proprioception and/or feedback that is inherent to tasks
Proprioception	Sense of that indicates whether the body is moving with the required effort, as well as where the various parts of the body are located in relation to each other.
Intrinsic knowledge of results	Knowledge of results that is available when tasks have knowledge of results “built into them”.
Augmented knowledge of results	Knowledge provided to learners after their completion of tasks relative to the goals of tasks
Augmented knowledge of performance	Knowledge of nature of movement, such as kinematic information about the movement pattern produced

Augmented feedback can have negative, as well as positive, effects. In general, both types of augmented feedback adhere to the same principles in the way that they affect motor skill learning (Schmidt, 1991; Swinnen, 1996; Wulf and Shea, 2004). It has been argued that no learner can acquire psychomotor skills without the presence of knowledge of results (Newell, 1974). However, numerous studies have examined the predictions of the “guidance hypothesis” which received its name from the role feedback is thought to play in guiding trainees to the correct movement. While this is undoubtedly a positive effect of feedback, frequent feedback can also have negative effects. Specifically, the learner might become too dependent on the augmented feedback and bypass the processing of other important intrinsic feedback sources s/he might rely on when the augmented feedback is withdrawn. Furthermore, frequent feedback during practice has been argued to result in less stable performance, as it prompts the trainee to adjust even small response errors that may simply represent an inherent variability in the motor system (e.g. Salmoni et al., 1984; Schmidt, 1991). It has been argued that although the guidance hypothesis contributed to a better understanding of how feedback affects performance and learning, future research needs to examine how feedback interacts with factors, such as task complexity, level of expertise, focus of attention, to influence learning (Wulf and Shea, 2004). Studies (e.g. Chiviacowsky and Wulf, 2002, 2005; Janelle et al., 1997; Janelle et al., 1995) suggest that giving learners the opportunity to decide when to receive feedback (i.e. self-controlled feedback) has generally enhanced their learning compared to not having this opportunity (i.e. yoked condition). Further, there is evidence that suggest learners prefer to receive feedback after they think they had a relatively successful trial but not when they think their performance was relatively poor (Chiviacowsky and Wulf, 2002, 2005). Moreover, there is evidence that suggests that learning is facilitated if feedback is provided after good, rather than poor, trials (Chiviacowsky and Wulf, 2007).

2.4 Psychomotor skills learning by people lacking basic skills

There are few references in the literature to the teaching of psychomotor skills to people who lack basic skills. Romiszowski (1984) reported that some work using videotape in the training of illiterates to perform industrial and agricultural tasks showed that the soundtrack was seldom necessary and sometimes caused more distraction than instruction. However, it is important to note that any study that involved the communication of psychomotor skills without the use of natural language is of some relevance. For example, one study compared verbal and nonverbal teaching of music. The findings from this study suggest that nonverbal instruction can lead to increased ear-to-hand skills and kinesthetic response skills (Dickey, 1991). Another study involved comparison of verbal and nonverbal instruction for mathematics. The findings from this study suggest that nonverbal instruction is a useful alternative to verbal instruction. Interestingly, the findings suggest that teacher talk may not be effective in enhancing learning (Hollingsworth, 1973).

There are many options for instruction without the use of natural language. For example, one study involved comparison of kinesthetic imagery with visual imagery. The results support the contention that the motor system can program closed skills more easily when the kinesthetic image of its later execution can be represented efficiently (Fery and Morizot, 2000). Another study involved comparison of visual with kinesthetic instruction for learning a gross motor skill. No difference in performance was found between the two instructional groups (Mount, 1987). Interestingly, one study found that speech only instruction of an assembly task was much longer than gesture only instruction of the same task (Krych et al., 2004). Another study found that gesture-only instructions were learnt more quickly than speech-only instructions. Further, gesture-only led to fewer assembly errors. Gestures demonstrating actions were found to be particularly crucial suggesting that the superiority of gestures to speech may reside, at least in part, in compatibility between gesture and action (Lozano and Tversky, 2006). Records from that research are shown in Figure 7 below.

Figure 7. Gesture only instruction.

2.5 Section summary

Psychomotor skills have been the subject of much research over many years by numerous scientist in different fields. Accordingly, psychomotor skills and the learning of psychomotor skills are the subject of many texts and papers. Factors most relevant to this study are listed below.

- Psychomotor skills can be fine-gross; open-closed; discrete-serial-continuos. The environments in which psychomotor skills are performed may be fixed, stable or moving.
- Innate abilities underlie the acquisition of all psychomotor skills. Psychomotor abilities include balance, limb speed, manual dexterity, muscle power, precision of movement, and spatial perception.

- Psychomotor skill is often referred to in terms of fine functioning and gross functioning.
- Psychomotor skill varies from individual to individual. In general, increased amounts of practice can compensate for lesser psychomotor ability.
- There are at least eight general taxonomies of the psychomotor domain. These include hierarchies such as: observation – trial – repetition – refinement – consolidation – mastery.
- There are at least three models of learning relevant to the acquisition of skill knowledge. These describe steps in the process of skill instruction such as: imparting knowledge content; imparting basic skills; and developing proficiency.
- The following factors are important to the instruction of psychomotor skills: task analysis; physical and mental practice; visual demonstrations and visual imagery; augmented feedback.
- There are many options for instruction of psychomotor skills without the use of natural language. Moreover, natural language may be a hindrance to the instruction of psychomotor skills.

3. Innovations in Skill Communication

In this section, an overview of innovations in skill communication is provided. First examples of innovations in the communication of skill knowledge are provided. These involve ambient intelligence; mobile/wearable computing; and multi-media. Subsequently, examples of innovations in the communication of skill training are provided. These involve multi-media; video, virtual reality and intelligent tutors.

3.1 Real-time skill knowledge via ambient intelligence

Ambient intelligence involves enriching an environment with technology (mainly sensors and devices interconnected through a network) in order to build a system that make decisions to benefit the users of that environment based on real-time information gathered and historical data accumulated (Augusto, 2007). Ambient intelligence can involve networks, sensors, interfaces, ubiquitous computing, persuasive computing, and artificial intelligence. An ambient intelligence system provides a digital environment that proactively and sensibly supports people in their daily lives. Here, sensible refers to the ability to give help when needed but refrain from intervention unless it is necessary. The terms, "smart environments" and "intelligent environments" can be used in connection with ambient intelligent. However, it is important to note that ambient intelligence is not necessarily restricted to a building or an indoor space.

There are few examples of ambient intelligence systems being used to communicate skill knowledge. Ubiquitous computing for educational environments is well established but these do not involve artificial intelligence. Rather, ubiquitous computing for education has been defined as teachers and students having access to technology, such as computing devices, the Internet, services) whenever and wherever they need it, and on-demand availability of task-necessary computing power. By contrast, ambient intelligence systems are distributed context-aware systems that should have the capability to identify a user of the system and the role that user plays within the system in relation to other users. It should be able to recognize the tasks users are performing in order to provide help if necessary. Further, it should be able to track what users and artifacts are where at what time. Also, it should be able to infer and understand intentions and goals behind activities. These functionalities have been tested to some extent in trials of proactive instructions (Michahelles et al., 2004). Further, as shown in Figure 8 below, Boeing have demonstrated how an assembly environment could be set up which would could communication some aspects of psychomotor skill knowledge (Dods, 2006).

Network Centric Manufacturing Demonstration

Network Centric Operations (NCO)/Assembly & Quality Technology

Cricket Mote Sensors: Keeps network appraised of assembly location, records key *as built* data, and locates critical items within the factory

RFID: Verifies tool calibration, material shelf life, and mechanic certification status.

Cognitive Agent: Performs dynamic/adaptive process monitoring. Provides *right* information to the *right* person at the *right* time.

Laser Projection: Displays engineering definition and defect location in the physical 3D workspace.

Indoor GPS (iGPS): Provides real time location data to *smart tools and to map defects.*

"Smart" Hand Tools: Network communicates location and process requirements to tool. During operation, tool communicates actual location and process variables to network. Network matches "as-defined" to "as-performed" process to verify/document operation.

Vision: Implement an event driven manufacturing system.

Figure 8. Boeing's vision.

For example, network communicates location and process requirements to "smart" hand tools. Knowledge of process requirements, or task requirements, could otherwise be part of the skill knowledge that a person would have to learn. Further the matching of "as-defined" to "as-performed" process or task, could otherwise be part of the augmented feedback provided by a human instructor. Boeing seeks to create intelligent tooling that no longer requires operators to set limits or torques for a specific operation. If successful, this would enable a person without relevant skill knowledge to carry out a task with the same accuracy as a person with skill knowledge, and perhaps with greater consistency.

Proactive Instructions The term proactive computing refers to the concept of people being serviced specifically according to their needs and current situation (Tennenhouse, 2000). Proactive Instructions are intended to overcome limitations of printed instructions. This can be achieved by attaching computing devices and multiple sensors onto different parts of the assembly. This enables recognition of the actions of the user and the current state of the assembly. It is argued that printed instructions are mostly linear and describe only one way to complete the task. For beginners this can be appropriate. However, for others this can be too restrictive and perhaps annoying. One approach is to immerse instructions into the objects of interest or the environment. For example, printers present instructions whenever a problem occurs they display just-in-time instructions for immediate assistance. However, such instructions are mostly static and unaware of the state of the environment and the user. By contrast, ubiquitous computing has the potential to connect the virtual world to the real world and provide opportunities for proactive, unobtrusive, and context-aware system which delivers just-in-time instructions during an assembly task. Three levels of instructions have been proposed. First, full-walk-through – for beginners who need full guidance. Second, assistance-on-demand for users who have some expertise and prefer to start without any instructions. Such users choose their own preferred order of performing actions but they know that the they have the possibility to inquire instructions at any point. Third, rescue-from-trap is designed for users who actually might know how to solve a certain task. They are experts and do not want to be annoyed with any guidance at all. Users will receive instruction if they break an important safety rule. Users also have the possibility to ask for assistance, if they feel they cannot proceed on their own (Antifakos et al., 2002). An example of Proactive Instructions is shown in Figure 9 (Michalles et al., 2004).

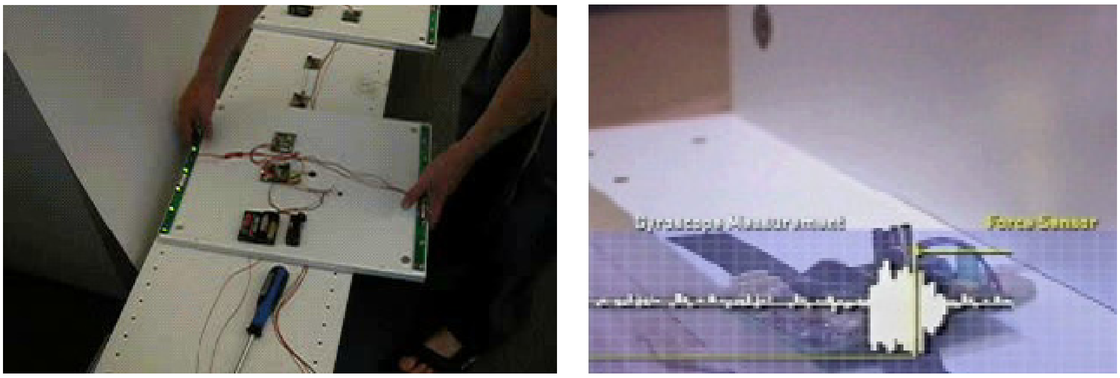


Figure 9. Example of Proactive Instructions. (Source: see page 82.)

3.2 Real-time skill knowledge via mobile/wearable computing

Mobile Computing is a generic term describing the ability to use technology ‘untethered’, that is not physically connected, or in remote or mobile (non static) environments. The term is evolved in modern usage such that it requires that the mobile computing activity be connected wirelessly to and through the internet or to and through a private network. This connection ties the mobile device to centrally located information and/or application software through the use of battery powered, portable, and wireless computing and communication devices. This includes devices like laptops with wireless LAN or wireless WAN technology, smart mobile phones, wearable computers and Personal Digital Assistants (PDAs) with Bluetooth or IRDA interfaces. Many types of mobile computers have been introduced since the 1990s, including the:

laptop computer; subnotebook; personal digital assistant; portable data terminal (PDT); mobile data terminal (MDT); tablet personal computer; smartphone.

Figure 10. AR headset. (Source: see page 82.)

The goal of wearable computing is to produce a synergistic combination of human and machine, in which the human performs tasks that it is better at, while the computer performs tasks that it is better at. A wearable computer can be described as a computer that is subsumed into the personal space of the user, controlled by the user, and has both operational and interactional constancy, i.e. is always on and always accessible. Most notably, it is a device that is always with the user, and into which the user can always enter commands and execute a set of such entered commands, and in which the user can do so while walking around or doing other activities. The most salient aspect of computers, in general, (whether wearable or not) is their reconfigurability and their generality, e.g. that their function can be made to vary widely, depending on the instructions provided for program execution. With the wearable computer, this is no exception, e.g. the wearable computer is more than just a wristwatch or regular eyeglasses: it has the full functionality of a computer system but in addition to being a fully featured computer, it is also inextricably intertwined with the wearer. This is what sets the wearable computer apart from other wearable devices such as wristwatches, regular eyeglasses, wearable radios, etc. Unlike these other wearable devices that are not programmable (reconfigurable), the wearable computer is as reconfigurable as the familiar desktop or mainframe computer. Examples of wearable computing are shown Figure 10 (augmented reality headset) and Figure 11.

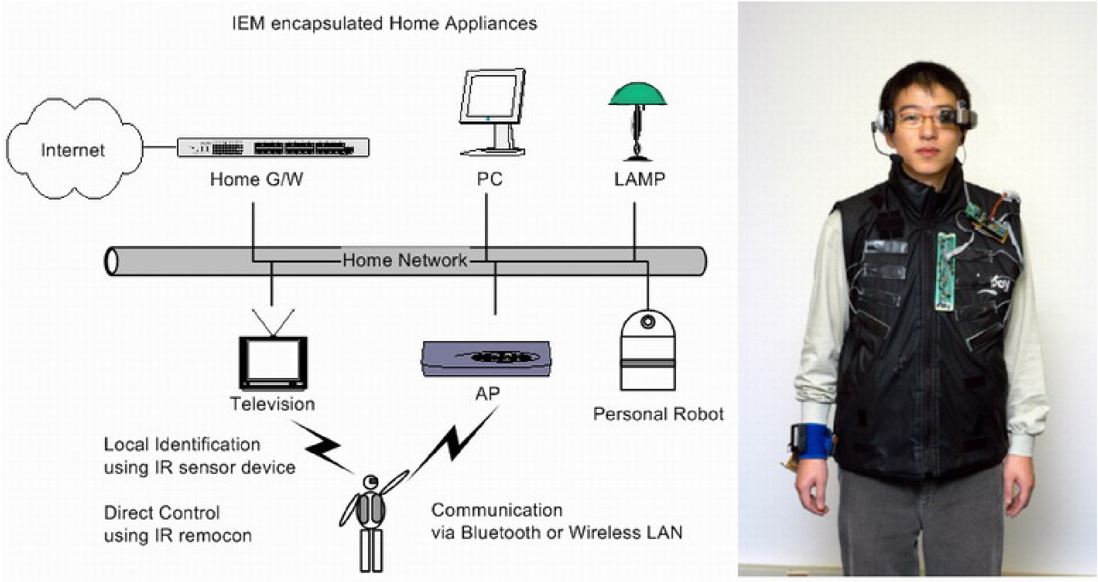


Figure 11. Example of wearable computing. (Source: see page 83.)

Wearable computing can be defined in terms of three basic modes of operation. First, constancy: the computer runs continuously, and is “always ready’’ to interact with the user. Unlike a hand-held device, laptop computer, or personal digital assistant (PDA), it does not need to be opened up and turned on prior to use. Second, augmentation: traditional computing paradigms are based on the notion that computing is the primary task. Wearable computing, however, is based on the notion that computing is NOT the primary task. The assumption of wearable computing is that the user will be doing something else at the same time as doing the computing. Thus the computer should serve to augment the intellect, or augment the senses. Third, mediation: unlike hand held devices, laptop computers, and PDAs, the wearable computer can encapsulate us. It doesn’t necessarily need to completely enclose us, but the concept allows for a greater degree of encapsulation than traditional portable computers.

Characteristics of wearable computing can be described as under the headings: photographic memory; shared memory; connected collective human intelligence; personal safety; tetherless operation; synergistic combination of human and machine; quality of life. Descriptions are provided in Table 7 below (Nicolai et al., 2006). The support of working processes with mobile and wearable computing is not widespread but is well established. For example, Boeing and Airbus have supported the use of an augmented reality since 1990 (Nicolai et al., 2006). This involves the display of information directly into the field of vision of the technicians to eliminate the need for them to refer to paper documentation. Examples are shown in Figure 10 on the previous page and in Figure 1 on page 4.

Table 7. Characteristics of wearable computing.

Characteristics	**Description**
Photographic memory	Perfect recall of previously collected information.
Shared memory	The potential for two or more individuals may share in their collective consciousness, so that one may have a recall of information that one need not have experienced personally.
Connected collective human intelligence	In a collective sense, two or more individuals may collaborate while one or more of them is doing another primary task.
Personal safety	A personal safety system could be built into the architecture (clothing) of the individual.
Untethered operation	Wearable computing affords and requires mobility, and the freedom from the need to be connected by wire to an electrical outlet, or communications line.
Synergistic combination of human and machine	Over an extended period of time, the wearable computer begins to function as a true extension of the mind and body, and no longer feels as if it is a separate entity. This intimate and constant bonding is such that the combined capabilities of the resulting synergistic whole far exceeds the sum of either. Synergy, in which the human being and computer become elements of each other's feedback loop, is often called Humanistic Intelligence (HI).
Quality of life	Wearable computing is capable of enhancing day--to--day experiences, not just in the workplace, but in all facets of daily life. It has the capability to enhance the quality of life for many people.

Knowledge management has been combined with wearable computing to enable instant access to electronic log book, aircraft manuals and experience knowledge. A particular challenge of wearable computing is the design of proper user interfaces. User interfaces can be handheld and/or wearable. Augmented reality audio involves enriching a person's normal acoustic environment with virtual audio objects. In a portable device, environmental sounds are integrated with synthetically generated audio. Listeners can wear a headset configuration that includes a binaural microphone and stereophonic headphones. In addition to feeding sounds of the environment to the headphones, an auxiliary input can provide the means for reproducing recorded audio in a virtual space. Listening tests with a prototype system suggest that some experienced listeners find it difficult to distinguish between real and virtual sources (Tikander, 2005). Figure 12 below shows a vest for maintenance housing all components of a wearable computer developed for aircraft maintenance (Nicolai et al., 2006).

Figure 12. Wearable computing vest.

Haptic augmented reality involves reproducing the sense of touch when interacting with virtual objects displayed in an Augmented Reality environment. Collaborative haptic applications are possible. As shown in Figure 13 below, haptic augmented reality environments have been used to design, for example, cranial implants (Scharver et al., 2004).

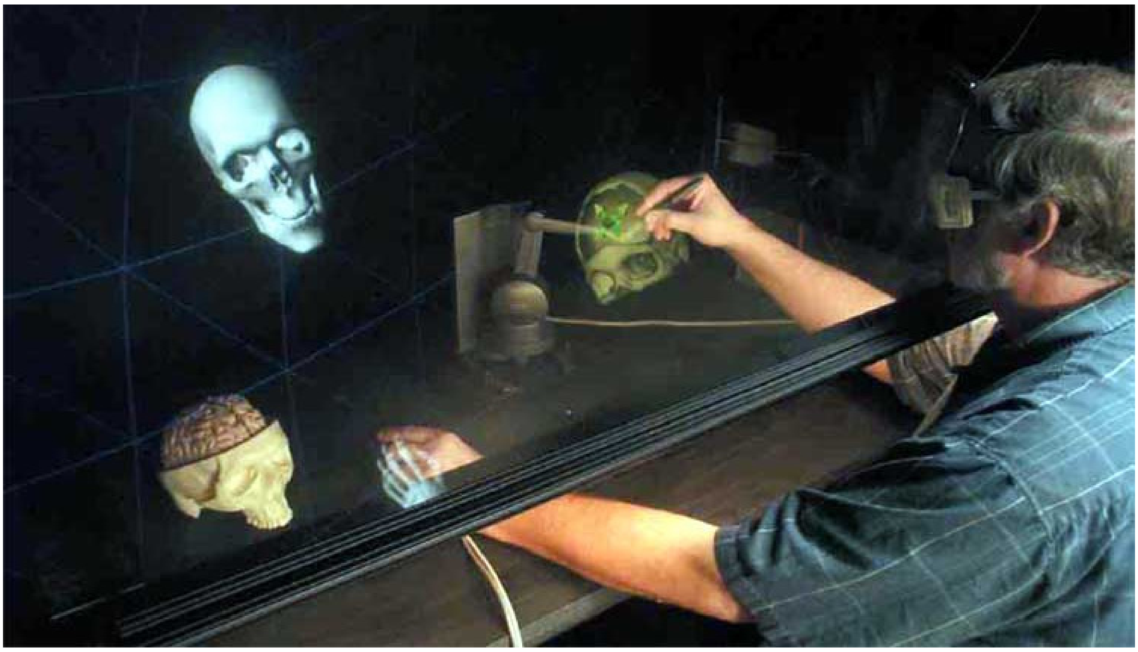


Figure 13. Haptic augmented reality.

3.3 Real-time skill knowledge via multimedia

Point-of-Use Information Resources support users in performing a task, providing access to required information and alternative forms of knowledge presentation through the use of text, images and interactive data presentation. A Point-of-Use Information source is used when the learning content is too extensive to retain mentally. Instead of training staff to carry large numbers of tasks, some of which they may never carry out, Point-of-Use Information Resources, such as an e-manual can provide all of the information required directly, at the time it is required for a particular task. This means that the user only makes reference to required information as and when it is needed – instead of overloading themselves with irrelevant information that may never be used. Point-of-Use Information Resources have been developed by the John Deere company (Trees, 2006). This company is a world leader in agricultural, construction, forestry and grounds care equipment. As shown in Figure 14 below, John Deere uses graphic views to communication important information.

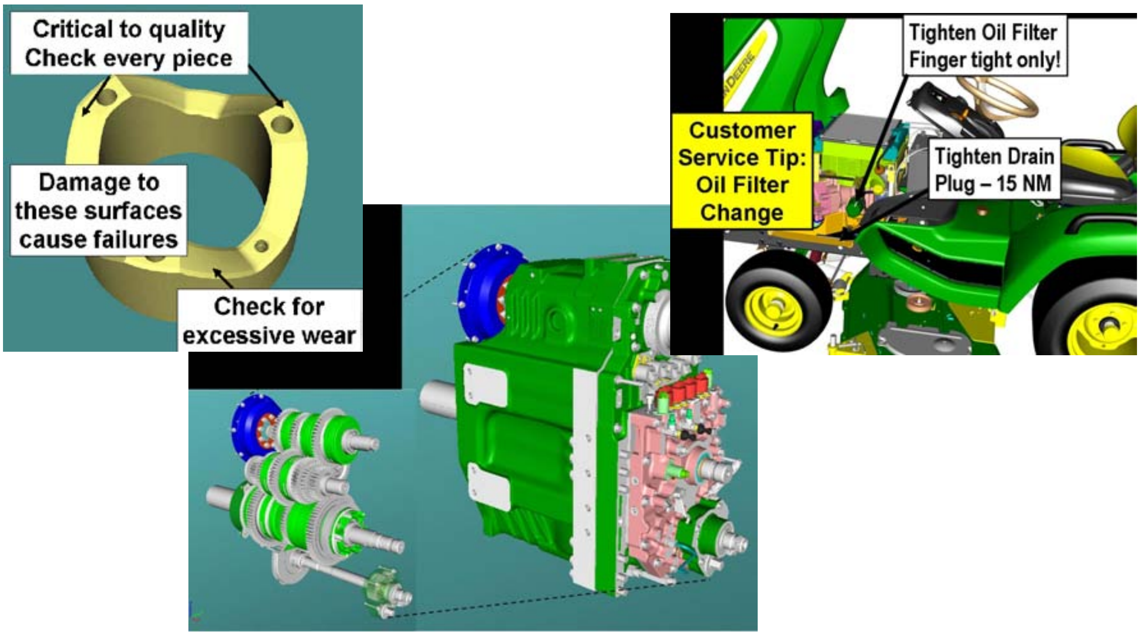


Figure 14. John Deere's graphical views.

The whole ethos of Point-of-Use Information Resources revolves around accessing the information when and where it is required. Therefore, the technology that is used must lend itself to an often challenging environment. These challenges can be include dirt, noise, lack of a network, need to regularly update the content. In the case of the United Kingdom's Command, Control, Communications, Computers and Intelligence network capability, great emphasis has been placed on the use of e-technologies to provide the solutions. Although the solutions use e-technologies, they are not always running over a network or intranet, as the networks available are used for more important information.

The solutions are delivered on CD-ROM or on laptops running a personal web server, with the future possibility of loading them on to networked systems if the need arises (Woodford, 2004). As shown in Figure 15 below, point-of-Use Information can be delivered through hands free wireless technology (Trees, 2006).

Figure 15. Hands free wireless information delivery.

3.4 Skills training on demand using multimedia

Just-in-Time Training is intended to provide people with the information they need for doing their jobs just when they need it. In doing so, what is learnt is used immediately rather than after some time when some of what had been learnt may have been forgotten. Different types of techniques and media are used with these new methods. Table 8 below show what techniques and media are used. Also, estimates of how much information is likely to be remembered are provided (Trotter, 2007).

Table 8. Media in new methods for information delivery and training.

Technique	Media	How much is remembered
Reading, e-reading	E-mail, e-documents	10%
Seeing	E-course with visual, online self-study guides, and online self-study guides, and online presentations	30%
Seeing and hearing	E-course with audio and video	50%
Saying or writing	Interactive live e-class or seminar	70%
Doing	Simulations and games	90%

Different mixes of media can make information required to perform a task easily available, thus reducing the need for prior training. The user decides when and where what information is needed and is driven by their need to complete the task. Hence removing the need for instructor led training. By replacing formal training, it also has the benefit to the user of putting fewer demands on their memory. More and more educational material is becoming openly available free on line as so called OpenCourseWare. Further, attempts are underway to try to establish a common technical framework for computer and Web-based learning that fosters the creation of reusable learning content as “learning objects” (Wisher, 2006).

Several computer technologies have converged to make training more dynamic. Just in Time Training (JITT) is intended to offer people: just the right information; at just the right time; with an appropriate modality; and presentation – for the user’s preferences, the importance of the information and the user’s current context. In particular, video compression and emerging standards for multimedia formats make it possible to create virtual classrooms on relatively inexpensive computers. Multi-media combines 3D visuals, animation, sound, text and interactivity to speed learning and increase retention. Internet broad-band access, wireless and satellite communications, and the World Wide Web provide connections from almost any place. Multi-modal systems process combined natural input modes, such as speech, pen, touch, hand gestures, eye gaze, and head and body movements, in a coordinated manner with multimedia system output. Technology that spans engineering and training departments can help turn product information and data into effective JITT content while reducing the expense and time previously associated with generating training content. By reusing design data, for example, a U.S. helicopter manufacturer discovered significant time reduction for creating maintenance training content for all aspects of a 300,000 part aircraft (Trotter, 2007). Although the initial costs of implementing JITT on-site can be significant, especially if implementing very specific and targeted training, the cost can be outweighed by subsequent improvements in productivity and/or the reduction in training time. JITT has become more accessible to users due to the widespread use of net technology and improvements in the understanding of how and when to use it. However, this can work against this form of training by making too much training available when time is limited. This is partially true if the training is not specifically targeted to the requirements. Also, the environment within which the training is delivered can work against this form of training. The place of work is not always the best place to learn, with the possibility of distractions being much greater. Research in this area has sought to bring together researchers from areas such as workflow, personalization and tutoring strategies.

Instructional games and simulations, can accelerate learning, greatly increase transfer-of-training to the job, and build job-related problem resolution skills. In particular, it has been argued that video games provide scenarios that challenge and engage (BBC, 2002). Instructional games and simulations are a major application area for Instructional Systems Technologies (IST). This field includes analysis, design, development, evaluation, and implementation/management of instructional systems and other learning environments. IST theoretical research is interdisciplinary, encompassing: instructional design theories and models; learning and cognition; instructional strategies and tactics; visual design, media design, and interaction design; usability testing and evaluation; educational systems design; production and management systems; and human performance improvement. Overall, the advances in computer, communication and Internet technologies that have revolutionized ways people communicate, retrieve and employ information and ways learning and instruction are carried out. Moreover, the same technological advances have afforded new theoretical insights into the fields of learning and instruction.

3.5 Skills training using video

Videos allow users to view live, fluid motion of an expert performing a motion, and is a well established medium for instruction (McNeal and Nelson, 1991). Learning through the use of video can be maximized by procedures such as: watching in short segments; taking notes; stopping the video to trying to predict/recall what will happen next; turning sound off and providing own narration; using rewind function to master one segment before proceeding to next. Using video as a form of performance feedback can be an effective tool to improve motor skill learning (Darden, 1999). For learning full body motions, video learning has been compared unfavourably with immersive virtual reality. It has been argued that immersive virtual reality extends the affordances of video by allowing the user to enter the same world as the teacher. Also, video has been criticized for not allowing users to change camera position and orientation. In addition, video has been criticized because it allows users to only watch the instructor. By contrast, immersive virtual reality allows users to interact with the instructor an environment, as well as to perform novel functions such as sharing body space with the instructor (Patel et al., 2007). On the other hand, video is a widely available and low cost technology. In particular, video has proved to an effective media for capturing and communicating skill knowledge in Jamaica, India, Peru, Mali and Mexico (Dagron, 2001). In particular, Video SEWA India refers to the use of video training as “Learning by Seeing”.

3.6 Skills training using virtual reality

Virtual reality has potential to enable flexible on-demand training (Mantovani et al., 2003). Virtual training has been applied to training in aviation (e.g. flight and space simulators; military (e.g. mission training); medicine (e.g. invasive surgery); emergency (e.g. fire fighting and paramedics); and art (e.g. calligraphy) Virtual environments include digital simulations that involve representations of teachers, students and content for learning applications. There use is well established in the instruction of tasks to be carried out in hazardous environments (Moorthy et al., 2005). There use is also well established in the instruction of specific skills used in everyday environments. Figure 16 below shows a virtual environment circa 1997 for teaching people how to operate a bulldozer. Virtual reality training environments are available for the learning of specific psychomotor skills such as welding. Figure 17 below shows a virtual reality training system. This consists of a welding torch attached to a force feedback device, a head-mounted display, a six-degrees-of-freedom tracking system for both the torch and the user’s head, and external audio speakers. Trainers can monitor the speed and angle at which the trainee is welding, as well as the amount of energy being put out.

Figure 16. Virtual training circa 1997. (Source: see page 83.)

Figure 17. Virtual reality training circa 2007. (Source: see page 83.)

Real-time interaction can take place between users and virtual environments (Bailenson et al., in press). In principle, people can interact with a virtual environment by using any perceptual channel, including visual (e.g. by wearing a head-mounted display with digital displays that project virtual environments), auditory (e.g. by wearing earphones that help to localize sound in virtual environments), haptic (e.g. by wearing gloves that use mechanical feedback or air blasts systems that simulate contact with objects in virtual environments, or olfactory (e.g. by wearing a nosepiece or collars that release different smells when a person approaches different objects in virtual environments). There is some evidence that training with a virtual reality simulator can accelerate the development of hand-eye skills (Tuggy, 1998).

An immersive virtual environment (IVE) is one that perceptually surrounds the user, increasing his or her sense of presence or actually being in it. When a person moves within a IVE, tracking technology senses this movement and renders the virtual scene to match the user's position and orientation. Moreover, sensory information from the physical world is kept to a minimum. For example, in an IVE that relies on visual images, the user wears a head-mounted display or sits in a dedicated projection room. By doing so, the user cannot see the objects from the physical world, and consequently it is easier for them to become enveloped by the synthetic information. There are two important features of IVEs. The first is that IVE's necessarily track a user's movements, including body position, head direction, as well as facial expressions and gestures. As a result, a wealth of information is provided about where in the IVE the user is focusing her/his attention; what he observes from that specific vantage point, and his reactions to the environment. The second is that the designer of an IVE has much control over the user's experience, and can alter the appearance and design of the virtual world to fit experimental goals, providing a real-time adjustments to the specific user's actions. Nonetheless, the photorealism and behavioral realism of IVEs are not equivalent to a "real world" experience. A vision-based tracking system provides information about a user's head and hand position in real-time. Hand tracking allows the user to interact with the virtual characters using natural gestures such as pointing and hand shaking. Head tracking allows rendering of the virtual character from the perspective of the user. Figure 18 below shows a training situation in which head tracking data shows where the medical student is looking.

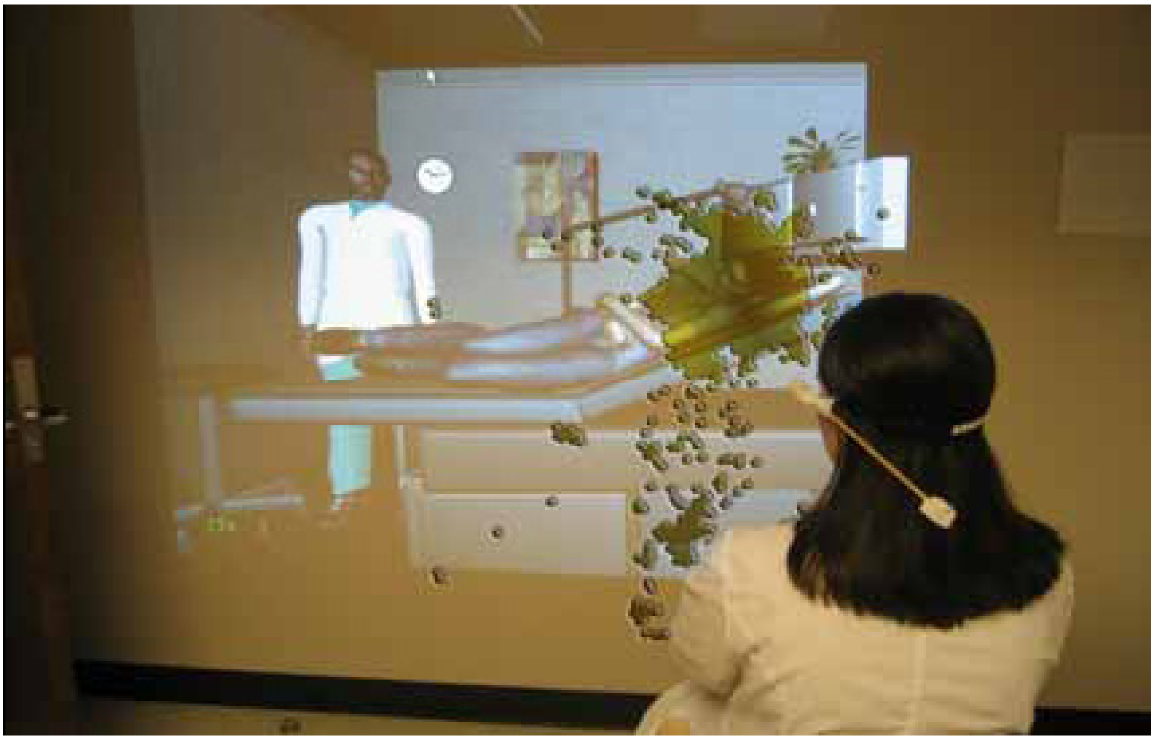


Figure 18. Virtual reality head tracking. (Source: see page 83.)

Collaborative virtual environments (CVEs) involve more than a single user (Rickel an Johnson, 1999). CVE users interact via avatars. An avatar is a digital representation of a user in virtual reality environment. The word comes from Hindu mythology in which spirits come down and inhabit bodies. For example, while in a CVE, as Person A communicates verbally and nonverbally in one location, the CVE technology can nearly instantaneously track his or her movements, gestures, expressions and sounds. Person B, in another location, sees and hears Person A's avatar exhibiting these behaviours in his own version of the CVE when it is networked to Person A's CVE. Person B's CVE system then sends all of the tracking information relevant to his own communications over the network to Person A's system, where then renders all of these movements via Person B's avatar, which Person A can see and hear. This bidirectional process – tracking the users' actions, sending those actions over the network, and rendering those actions simultaneously for each user – occurs at extremely high frequency (e.g. 60 HZ). There is some evidence that augmented feedback presented in a virtual environment can accelerate learning of a difficult psychomotor task. In particular, when the movement of an expert is superimposed on the learner's movement and the two movements are displayed concurrently (Todorov et al., 1997).

3.7 Skills training using intelligent tutoring systems

Intelligent tutoring systems can be defined as educational software containing an artificial intelligence component. The software can track students' work, tailoring feedback and hints along the way. By collecting information on a particular student's performance, the software can make inferences about each particular student's strengths and weaknesses, and can suggest additional work. Figure 19 below shows the Surface Warfare Officers School (SWOS), where the U. S. Navy trains officers to serve as tactical action officers (TAOs) on U.S. warships.

Figure 19. Advanced intelligent tutoring system. (Source: see page 83.)

This advanced simulation-based intelligent tutoring system controls the ship's weapons and sensors and directs the movements of the ship, other support vessels, and aircraft. The TAO monitors the movements and actions of ships, planes, missiles, and submarines in the region. The TAO integrates this information in real time to form a dynamic tactical picture, select appropriate responses, and issue orders. The simulation-based intelligent tutoring system (ITS) enables students to act as TAOs in tactical simulations. The simulation's graphical user interface displays a geographical map of the region and provides rapid access to the ship's sensor, weapon, and communication functions (Stottler et al., 2007). After the student completes a scenario, the intelligent tutoring system evaluates the entire sequence of student actions to infer tactical principles that the student applied correctly or failed to apply. These principles are detected according to sophisticated, temporal pattern-matching algorithms defined by the instructor using the system's graphical user interface. The system is highly configurable, and authoring tools enable the instructor to define new types of ships and aircraft, scenarios, and principles. The instructor can also define complex behaviors for each friendly and enemy ship and aircraft to create realistic, multi-agent simulations. Further, the system employs hierarchical finite state machines to control the behaviors of other simulated entities as well as to detect significant patterns of actions, events, and state conditions to monitor the student's actions, evaluate the appropriateness of their actions, and assess their skills.

Intelligent tutoring systems often include speech-enabled interfaces. In this case for example, the speech-enabled graphical user interface more accurately represents how a TAO actually works on board a Navy ship by enabling the student to converse with simulated crew members to issue commands and receive information. Also, this advanced intelligent tutoring system employs intelligent agents, rather than instructors, to play the roles of simulated crew members. This reduces the staff overhead required to conduct effective TAO training. Further, the system automatically evaluates the student's performance in real-time and infer tactical principles that were applied correctly, or not applied, so it can coach the student during each scenario. Overall, applications simulation-based intelligent tutoring systems complement traditional classroom or computer-based training by enabling students to practice the application of concepts and principles within realistically-complex scenarios. The technologies employed by the TAO training system are especially useful for developing interactive simulation-based training systems that run multi-agent and/or real-time scenarios for military training, computer games. As illustrated in Figure 20 below, there are lower cost options for intelligent tutoring systems. Their interfaces can be viewed through single screens during both their configuration and their use.

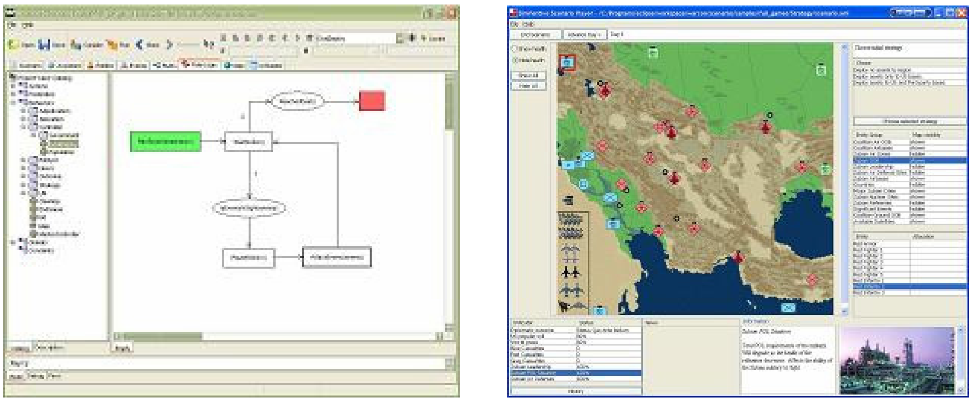


Figure 20. Affordable intelligent tutoring systems. (Source: see page 83.)

3.8 Section summary

There have been many innovations which have some potential to enable the real-time communication of psychomotor skills to people who are lacking in basic skills. Important examples are listed below.

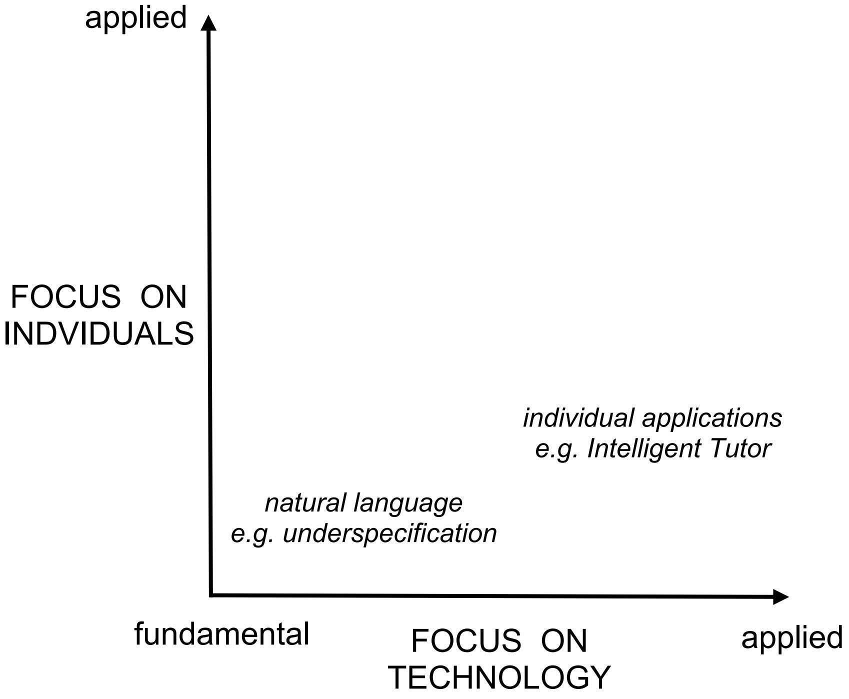
- Ambient intelligence has the potential to enable the introduction of intelligent tooling that no longer requires operatives to set limits or torques for specific operations. This would enable a person without relevant skill knowledge to carry out a task with the same accuracy as a person with skill knowledge, and perhaps with greater consistency.
- Ambient intelligence has the potential to enable proactive instructions. For example, recognition of the actions of users and the current state of assembly could enable the delivery of just-in-time instructions. This would enable a person without relevant skill knowledge to carry out a task with equal, or better, information to a person with skill knowledge.
- Mobile and wearable computing enables instant access to a more skill knowledge than individual people can retain in their memories. Accordingly, mobile and wearable computing has the potential to enable people to carry out skilled work in a wide variety of industries.
- Multimedia has the potential to facilitate effective just-in-time training and point-of-use information. Moreover, information developed during product design can be used as the basis for multimedia just-in-time training and point-of-use information.
- Video technology is used extensively throughout the World to communicate psychomotor skills. Technological innovations and organizational innovations have been used to improve the utility of video in providing initial instruction and augmented feedback.
- Immersive reality environments can be extremely effective in the communication of psychomotor skills. However, virtual reality environments require considerable resources to set up and operate.
- Intelligent tutoring systems collect information on students' performance during training and make inferences about each student's strengths and weaknesses. Based upon these inferences, tutoring is tailored to each student's particular needs. Intelligent tutoring systems can be used with a range of media from immersive simulations to single computer monitors.

4. Overview of Computational Semantics

Computational semantics is recognized as being an important enabler for innovations that have the potential to facilitate the real-time communication of skill knowledge. In particular, for ambient intelligence systems (Gurevych and Mullhäuser, 2006; Tafat et al., 2004); for mobile and wearable computing (e.g. Bohus and Rudnicky, 2005); for virtual training environments (e.g. Kenny et al., 2007); and for Intelligent Tutoring Systems (e.g. Pon-Barry et al., 2005). More generally, it has been proposed that realizing the full potential of JITT will involve semantic indexing of the documents so that their access can be made flexible (Davis et al., 2003). Further, computational semantics is essential to the content-based retrieval of images that can be used in conjunction with a wide variety of media for the communication of skill knowledge (Belkhatir et al., 2005; Janvier et al., 2005). Also, it has been recognized for some years that semantic representations are essential to the functioning of multi-modal multi-media systems that could be used to communicate skill knowledge (Bunt and Romary, 2005; Flank, 1995). Computational semantics is concerned with the computation of meaning. For example, computational semantics can involve automating the association of semantic representations with expressions of natural language; and automating the process of drawing inferences from semantic representations. In this section, the current scope of computational semantics is described. Then, a generic description for computational semantics applications is presented. Subsequently, a generic description for the development of computational semantics applications is provided.

4.1 Current scope of computational semantics

To date, both fundamental and applied computational semantics have focused largely upon natural language. The term, natural language, encompasses all of the languages used by human beings to speak to each other. The term does not encompass artificial languages, such as computer languages, that are developed by people and may be modelled to some extent on examples of natural language. Further, natural language does not encompass languages which may be used by animals to communicate with each other. In particular, computational semantics has focused upon spoken and written natural language. Research concerned with spoken language has extended to vocal cues such as rate, pausing, pitch and silence. To date, computational semantic scientists have explored fundamental questions including: what kinds of semantic representations are suitable for capturing the meaning of natural language; how can the process of associating semantic representations with expressions of natural language be automated given the ambiguities inherent in natural language; how can the process of drawing inferences from semantic representations be automated? Findings from fundamental research have contributed to the development of computational semantics applications including information retrieval, information extraction, spoken dialogue systems and intelligent tutors. The development of applications has involved computational pragmatics as well as computational semantics. Computational pragmatics has been defined as the computational study of the relation between utterances and context. This means that computational pragmatics is concerned with the relation between utterances and action; with the relation between utterances and discourse; and with the relationship between utterances and the place, time, and environmental context of their being uttered. An introduction to computational semantics is provided by Blackburn and Bos (2005). Figure 21 below provides a diagrammatic illustration of computational semantics to date.



COMPUTATIONAL SEMANTICS – to date

Figure 21. Computational semantics – to date.

Thus far, applications of computational semantics have been for use largely by individuals to improve the performance of individuals. In the future, the development of the, so called, semantic Web could provide an application of computational semantics which could be used by any individual and any organization anywhere in the World (Akkiraju et al., 2005). However, generic computational semantics applications, which particular organizations could configure to meet their own specific needs, have yet to be a major consideration in computational semantics research and development work.

4.2 Components of computational semantics applications

There are a number of components that are common among computational semantics applications. These include: ontology; automated process of associating semantic representations; automated process of drawing inferences from semantic representations; communication processing devices. An overview of these common components is provided in the following paragraphs.

Ontology can be defined as an explicit specification of a conceptualization (Gruber, 1993), or the specification of one's conceptualization of a knowledge domain. In particular, ontology defines (specifies) the concepts, relationships, and other distinctions that are relevant for modeling a domain. The specification takes the form of the definitions of representational vocabulary (classes, relations, etc.), which provide meanings for the vocabulary and formal constraints on its coherent use (Gruber, 2008). Ontology resemble faceted taxonomies but use richer semantic representations among terms and attributes, as well as strict rules about how to specify terms and relationships. Ontology do more than control a vocabulary and hence can be thought of as knowledge representation. Ontology can be machine-readable and allow applications to be standardized while domain-specific information can be customized over time. Ontology aim to move the complexity of a system into how the information is organized rather than in the application that processes that information (McGuinness, 2003). Ontology can be principally communicative ontology or principally domain ontology. Communicative ontology define (specify) the concepts, relationships, and other distinctions that are relevant for modeling communication in many domains. Communicative ontology such as DAMSL (Dialogue Act Markup using Several Layers) provide a useful starting point for the development of application-specific communicative ontology. Communicative ontology, such as DAMSL, enable dialogue mark-up. The term dialogue mark-up refers to annotating dialogues with information about the communicative acts involved (Bunt, 2006). Utterances in dialogue can often be multifunctional. Hence more than one tag may need to be assigned to an utterance. This is often referred to as multidimensional annotation. For example, a question such as "what on Earth is that" can also be an exclamation of surprise. Domain ontology define (specify) the concepts, relationships, and other distinctions that are relevant for modeling specific domains. Domain ontology facilitate the association of semantic representations within specific domains. A domain can be specific to one type of location and one type of user. For example, domain ontology for interactive navigation systems can be specific to cars and to car users. Alternatively, domain ontology can be specific to one type of activity that can involve many types of locations and many types of users. For example, domain ontology for interactive meeting assistants are specific to meetings, but meetings can be held almost anywhere and involve almost any type of people.

Automated process of associating semantic representations can involve numerous interrelated analyses. There are two general approaches to these analyses: (i) grammar-based and (ii) classification. Each has its relative strengths and weaknesses. In particular, grammar-based approaches need more expertise but less training data. By contrast, classification approaches need less expertise but more training data. This is because human expertise is replaced by machine learning. As illustrated in Figure 22 below, there are numerous methods/tools available for analyses. These are informed by ontology. Syntactic analyses of communications can often involve parsing. A parser is a program that assigns syntactic structure. Parsing is a method: a parser is a tool. A parser can take a stream of words and give it syntactic structure. Parsers can identify, for example, noun phrases and verb phrases.

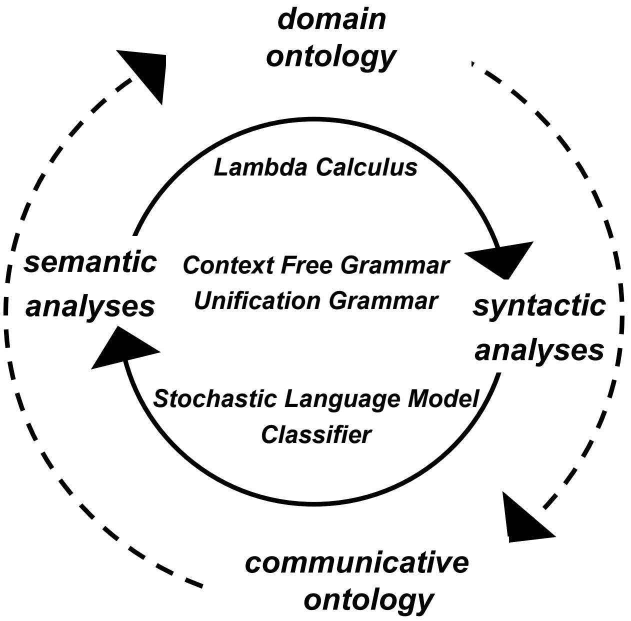


Figure 22. Potential methods/tools used in associating semantic representations.

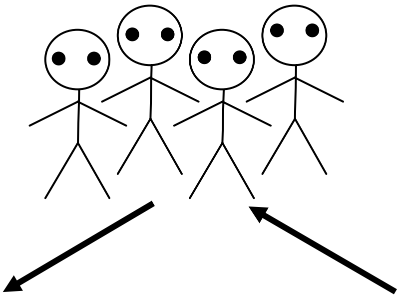
Parsing can involve the transformation of input into a data structure, usually a tree, which is suitable for classification and consequent annotation with semantic tags. Research into parsing seeks to increase accuracy without overly increasing the number of analyses. Development seeks to speed up parsing speed (Djordjevic et al., 2007). Analyses may involve application of Lambda calculus in order to build propositional representations. Analyses may involve rule-based grammars. For example, Context-Free Grammar (e.g. Lee et al., 2006) or Unification grammar (e.g. Hagoort, 2005). The context-free grammar (CFG) formalism was developed by Noam Chomsky in the 1950's. A context-free grammar provides a simple and precise mechanism for describing the methods by which phrases in some natural language are built from smaller blocks. The disadvantage is that important features of natural language such as agreement and reference cannot be easily expressed. Unification grammars can encompass multimodal inputs such as gesture as well as natural language.

Classification approaches use knowledge of features to determine what something is and to enable annotation of data structures (generated during parsing) with semantic tags. This can involve annotating dialogues with information relating to domain concepts, and/or with information relating to communicative concepts such as prosody. Accordingly, knowledge of features may be derived from domain ontology or communicative ontology. Analyses may involve stochastic language models (SLM) or so called classifiers including Support Vector Machines (SVM). Stochastic language models are more flexible than CFGs as they can work with less exact inputs such as mispronounced or misspelt words. SLM assign a most probable classification to an object based on a probability model developed through observation of, for example, the language used by domain-experts during their work. However, it is important to note that all grammars "leak" to some extent. In other words, no grammar is capable of dealing with every aspect of every communication that an application may encounter. Probabilities are calculated using well established techniques such as maximum entropy (Nigam et al., 2000). So called classifiers such as SVM make use of pattern recognition algorithms and are under continual development. In natural language processing, text is classified. However, classification is not limited to text and has been applied, for example, to geographical data (Estivill-Castro, 1997). The different methods and tools which may be used during analyses make use of representations such as first-order logic, discourse representation structures, and description logic. Due to the ambiguities with natural language, so called underspecified semantic representations are used. However, it is important to note, that the output from analyses will often be a set of semantic hypothesis rather than the association of one definitive semantic representation from which only one possible course of action can be inferred as being appropriate.

Automated process of drawing inferences from semantic representations involves automated reasoning. Dialogue management provides examples of how inference is used within computational semantics applications. A dialogue manager is the core component of a dialogue system. It maintains the history of the dialogue, adopts certain dialogue strategy, retrieves content (stored in files or databases), and decides on best responses to the user. The dialogue manager maintains the dialogue flow. Hence, in the early stages of a conversation the role of the dialogue manager might be to gather information from the user, possibly clarifying ambiguous input along the way so that, for example, a complete query can be produced for the application database. The dialogue manager must be able to resolve ambiguities that arise due to recognition error or incomplete information. (Zue and Glass, 2000). In later stages of the conversation, after information has been accessed from the database, the dialogue manager might be involved in some negotiation with the user. For example, if there were too many items returned from the database, the system might suggest additional constraints to help narrow down the number of choices. In addition to these two fundamental operations the dialogue manager must also inform and guide the user by suggesting subsequent sub-goals; offer assistance upon request; help relax constraints or provide plausible alternatives when the requested information is not available; and initiate clarification of sub-dialogues for confirmation. Some dialogue managers may seek to echo (i.e. ape) user. The overall goal of the dialogue manager is to take an active role in directing the conversation towards a successful conclusion for the user (Zue and Glass, 2000). So called, affective dialogue managers process the user's emotional state as well as the user's actions (Bui et al., 2006). It is important to note that dialogue management involves more pragmatic inference than semantic inference.

Communication processing devices include devices for speech recognition and speech synthesis. Speech recognition is the process of converting an acoustic signal, captured by a microphone or a telephone, to a set of words. Speech recognition should be able to process prosody. This term refers to acoustic structure that extends over several segments or words. Stress, intonation, and rhythm convey important information for word recognition and the user's intentions (e.g., sarcasm, anger). The recognized words can be the final results, as for applications such as commands and control, data entry, and document preparation. They can also serve as the input to further linguistic processing in order to achieve speech understanding, a subject covered in section. An isolated-word speech recognition system requires that the speaker pause briefly between words, whereas a continuous speech recognition system does not. Spontaneous, or extemporaneously generated, speech contains disfluencies, and is much more difficult to recognize than speech read from script. Some systems require speaker enrollment. In other words, a user must provide samples of his or her speech before using them, whereas other systems are said to be speaker-independent, in that no enrollment is necessary. Some of the other parameters depend on the specific task. Recognition is generally more difficult when vocabularies are large or have many similar-sounding words. When speech is produced in a sequence of words, language models or artificial grammars are used to restrict the combination of words. The simplest language model can be specified as a finite-state network, where the permissible words following each word are given explicitly. More general language models approximating natural language are specified in terms of a context-sensitive grammar. One popular measure of the difficulty of the task, combining the vocabulary size and the language model, is perplexity. Loosely defined, this is the geometric mean of the number of words that can follow a word after the language model has been applied. Finally, there are some external parameters that can affect speech recognition system performance, including the characteristics of the environmental noise and the type and the placement of the microphone. (Zue et al., 1996). Speech synthesizers are used, together with speech recognizers, in conversational agents that conduct dialogues with people. Synthesizers are also important in non-conversational applications that speak to people, such as in devices that read out loud for the blind, video games, children's toys etc. Further, people who cannot talk can type into a speech synthesizer and have the synthesizer speak out words. Speech synthesis can achieve quite natural speech for a very wide variety of input situations. Multimodal speech synthesis deals with automatic generation of voice and facial animation from text. Applications span from research on human communication and perception, via tools for the hearing impaired, to multimodal agent-based user interfaces. A view of the face can improve intelligibility of both natural and synthetic speech significantly, especially under degraded acoustic conditions. Moreover, facial expressions can signal emotion, add emphasis to the speech and support the interaction in a dialogue situation.

System architecture can be described as the set of relations between the parts of a system. The systems architecture of computational semantics applications are often presented in simple diagrams in papers which provide details of particular applications (e.g. Weng et al., 2006). A generic overview of spoken dialogue systems is shown in Figure 23 on the next page. This overview illustrates how the common components described above work together. For brevity, linear representations are used in this figure. However, it is important to note that the functionalities of the components of computational semantics applications can be integrated and iterative (e.g. Dowding et al., 1994). Indeed, the various components described in the preceding paragraphs can be thought of as a close “team of experts” who take up more or less work depending as the need arises. The “team of experts” can have overlapping expertise, and each can be more or less useful within the same application depending on the nature of different communications that each application encounters. For example, parsing may be of limited relevance in a one word utterance.



Request(s) for particular piece(s) of music	*Communication(s)* ***to*** *person(s)*
↓	↑
SPEECH RECOGNITION DEVICE	**SPEECH SYNTHESIS DEVICE**
↓	↑
automate process of associating semantic representation(s) with communication(s) *from person(s) in accordance with* ***music selection domain ontology developed through computational semantics***	***automate process of associating text with semantic representation(s)*** *from e.g. dialogue management in accordance with* ***domain ontology developed through computational semantics***
↓	↑
Useful semantic representation(s)	**Useful semantic representation**
↓	↑
automate process of drawing inferences from semantic representation(s) *in accordance with* ***communicative ontology developed through computational pragmatics***	***automate process of drawing inferences from updated contextual representation*** *in accordance with* ***communicative ontology developed through computational pragmatics***
↓	↑
Updated contextual representation	**Updated contextual representation**
↓	↑
use of artificial language to send a query to music database in accordance with ***music selection domain ontology developed through computational semantics***	*use of artificial language to send a response from music database in accordance with* ***music selection domain ontology developed through computational semantics***
↓ ——————————————→	↑

Figure 23. Generic overview of spoken dialogue systems for music selection.

The useful semantic representations referred to in Figure 23, may be a ranked list of semantic hypotheses expressed in a language which can be used directly by the computer or in an intermediate language. In either case, the process of analyses is intended to bring about disambiguity. That is to make semantic representations as unambiguous as possible. The updated contextual representation referred to in Figure 23, may be an updated history of the dialogue between human users and the spoken dialogue system for music selection. Figure 24 below provides a generic summary of phases that are common among computational applications.

Figure 24. Common phases in computational semantics applications.

In Figure 24, common phases are shown to be human input; multiple analyses; semantic annotation; pragmatic inference; machine control; and computer output. To date human input has often been in the form of natural language. As illustrated in Figure 22, analyses can be based on grammar or classification approaches. Annotation with semantic tags is common in the association of semantic representations. Pragmatic inferences are drawn from semantic representations. Subsequently, the computational semantics application will control equipment and devices (i.e. machines) that are relevant to the particular application and the specific human input. A spoken dialogue system for music selection will control, for example, DVD player, speakers etc. Machine control is then the mechanistic result of pragmatic inference. From this control phases will come computer output such as the music which the human input indicated was required. Alternatively, the computer output could be a spoken query through the speech synthesizer controlled by the computational semantics application. It is important to note that the diagram shown in Figure 24 provides an extreme simplification. In particular, the phases shown are often likely to be overlapping and iterative rather than separate and individual.

4.3 Development of computational semantics applications

There are activities which are common to the development of computational semantics applications. The early stages of development can often involve typical systems analysis activities. In particular, computational semantics scientist will have to learn about the real world domain of interest. For example, when developing an Intelligent Tutoring application, the scientist will need to learn about general strategies for tutoring. Further, the scientist will need to learn about the specific application domain. For example, when developing an Intelligent Tutor for ship handling, the scientist will need to learn about ship handling. Furthermore, the scientist will need to learn about the communication procedures, jargon, prosody etc., which are prevalent in ship handling. In addition, the computational semantics scientists will need to learn about the working of devices that will be used in the application. For example, devices for speech recognition, speech synthesis, visualization etc. Computational semantics scientists represent what they learn using block diagrams, flow charts etc. As illustrated in Figure 25, they will model the underlying activity that is to be engaged in by users of the application. Also, they will model the system, and component devices, that will be interacted with during that activity. Moreover, computational semantics scientist will model how communication processes will embody the interactions involved in that activity. All together this enables the formulation of preliminary systems architecture for the particular application.

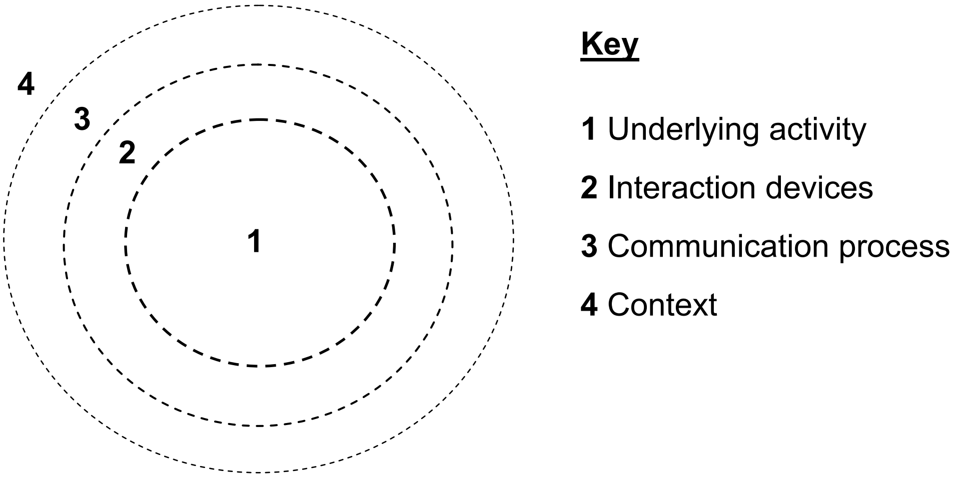


Figure 25. Initial modelling in development of computational semantics applications.

Computational semantics applications can be developed through configurable modular systems architectures. This enables initial components to be developed concurrently by different contributors. Further, new components can be added as the scope of an application develops. Moreover, components can be enhanced over time as computational semantics advances and/or greater resources become available. For example, the Conversational Helper for Automotive Tasks (CHAT) described by Weng et al. (2006) has a modular architecture that has facilitated its development from a music selection application to an application encompassing restaurant finding and vehicle navigation. It is important to note, that different systems architectures can be developed to enable the realization of different strategies. For example, the strategy for an in car dialogue system may be to associate a semantic representation to all of the communications which it encounters. By contrast, the strategy for an intelligent meeting assistant may be to only associate a semantic representation to certain aspects of the communications which it encounters (Purver et al., 2007).

Machine learning can radically reduce the need for human expert input into the development of computational semantics applications. The term, machine learning, refers to the ability of a program to learn from experience. In other words, to modify its execution on the basis on newly acquired information. Machine learning techniques include Markov models; neural networks; transformation-based learning; decision tree classification; and vector-based clustering (Hu and Atwell, 2002). Machine learning techniques have been applied to classification, to parsing, and to dialogue management. All of these can involve applying machine learning algorithms to corpora. The term, corpora, refers to sets of texts. When developing computational semantics applications, texts may be created during investigation of how communication processes will embody the interactions involved in the activity of interest. Classifying and parsing will often take place at the level of word and sentence. Analysis of dialogues analysis goes beyond sentence-boundaries. In a conversation, for example, meanings can refer back to previous sentences. Further, a series of turns between speakers generally has an overall structure to meet the goals of the participants. Machine learning techniques depend on having some initial “training examples” prepared by human experts to learn from. Nonetheless, the use of machine learning can greatly reduce: the need for computational semantics expertise in corpora analysis; the need for the annotation of corpora by people; the need for computational semantics expertise in the programming of classifiers, parsers and/or dialogue managers. Machine learning can be restricted to the development of computational semantics applications or can be deployed during their use. For example, machine learning techniques can be deployed to enable an application to learn from new instances during its use. This is can be referred to as “learning in the wild”.

4.4 Section summary

Computational semantics is recognized as being an important enabler for innovations that have the potential to facilitate the real-time communication of psychomotor skills to people who lack basic skills. Important topics are summarized below.

- To date, both fundamental and applied computational semantics have focused largely upon natural language. The development of applications has involved computational pragmatics as well as computational semantics.
- Ontology within computational semantics can be primarily communicative ontology or primarily domain ontology.
- Different methods / tools can be used during the analyses which enable the automated association of semantic representations. These methods / tools include

Lambda calculus; context-free grammars; unification grammars; stochastic language models; and so called classifiers.

- The output from analyses will often be a set of semantic hypothesis not the association of one definitive semantic representation from which only one possible course of action can be inferred as being appropriate.
- Drawing inferences from semantic representations involves automated reasoning. Dialogue managers can be used to automate the process of drawing inferences from semantic representations.
- Communication processing devices for computational semantics applications can include devices for speech recognition and speech synthesis.
- The development of computational semantics applications can often involve typical system analyses activities.
- Computational semantics applications often have configurable modular systems architectures.
- The development of computational semantics applications can involve the deployment of machine learning within the individual modules of configurable modular systems architectures.

5. Applying Computational Semantics

In this section, the potential for applying computational semantics to the real-time communication of psychomotor skills is discussed. In particular, the potential for applying the common components is considered. In conclusion, potential implications for computational semantics is discussed. The particular challenges of communication involving people without basic skills is considered throughout.

5.1 Communicative ontology

Communicative ontology define (specify) the concepts, relationships, and other distinctions that are relevant for modeling communication in many domains. Communicative ontology have, thus far, been largely concerned with natural language and enabling the markup of natural language. Nonetheless, the concepts, relationships, and other distinctions that are relevant to dialogues involving natural language may prove to be relevant to dialogues involving other modes of communication such as human gestures and visual languages. Such modes of communication will be important when seeking to communicate among people who lack basic skills such as literacy. For example, DAMSL includes top-level distinctions of four types of information, called layers: Forward-looking functions; Backward-looking functions, Information level, and Information status (Allen and Core, 1997). Forward-looking functions are subdivided into the following eight dimensions: statement, info-request, influencing-addressee-future-action, committing speaker future action, conventional opening or closing, explicit-performative, exclamation, other-forward-looking-function. Backward-looking functions, for example, are subdivided into the following four dimensions: agreement, understanding, answer, information-relation. Bunt (2006) proposes a taxonomy of communicative functions comprising eleven dimensions of dialogue acts: task/activity, auto-feedback, allo-feedback, turn management, time management, content management, own communication management, partner communication management, topic management, dialogue structuring, social obligations. Overall, so called layers and dimension within existing communicative ontology can provide very useful background information for the development of communicative ontology for dialogues that do not involve natural language. Further, the development of communicative ontology for visual, rather than natural, language has been considered for some years (Tanimoto, 1997). At a more fundamental level cognitive architectures, such as ACT-R, Soar, and Icarus (de Jesus, 2005), provide conceptual frameworks for creating models of how people perform tasks. An appropriate approach for the development of communicative ontology for real-time communication of skill knowledge may be to use cognitive architectures to model cases. Then, to relate those cases to existing communicative ontology in order to assess their relevance.

5.2 Domain ontology

Domain ontology define (specify) the concepts, relationships, and other distinctions that are relevant for modeling specific domains. Domain ontology facilitate the association of semantic representations within specific domains. The domain under consideration is the real-time communication of psychomotor skills to people without basic skills. The following concepts are important in this domain: psychomotor skills required by work task and work situation; existing level of psychomotor skill; level of natural language literacy; level of literacy in information and communications technologies (ICTs); fundamental capabilities of media. As described in earlier sections of this Working Paper, types of psychomotor skills are well defined. Also, the need to carry out task analyses to determine skill requirements is widely recognized. Further, the definition of different levels of tasks is well established in skills training. The peculiarities of a work situation can influence the amount of skill required to execute a task. For example, painting a pipe in a dusty work site may require more skill than painting a pipe in a clean factory. Levels of psychomotor skills are defined in the numerous taxonomies described above. Further, levels of literacy in natural language are defined, for example, within the citizenship language examination criteria of national governments. Levels of literacy in ICTs are not so widely documented. However, the National Educational Technology Standards for Students (NETS*S), produced by the International Society for Technology in Education (ISTE) offers a potential starting point defining ICT literacy levels (Thomas and Knezek, 2002). Fundamental capabilities of media have been defined (Dennis and Valacich, 1999) as immediacy of feedback (i.e. the extent to which a medium supports rapid bi-directional communication); symbol variety (i.e. the number of ways in which information can be communicated); parallelism (i.e. the number of simultaneous conversations that can exist effectively); rehearsability (i.e. the extent to which a medium enables the sender to rehearse or fine tune a message before sending); and reprocessability (i.e. the extent to which a message can be re-examined or processed again). Overall, the various domain concepts are already quite well defined. Moreover, the literature includes texts and papers containing advice about how to develop domain ontology (Devedzic, 2002; Hovy, 2005; Lopez et al., 1999; Poli, 2002). It is important to note that ontology are intended to move the complexity of a system into how the information is organized rather than in the application that processes that information. Clearly, there is considerable scope for complexity in determining what level of what type of psychomotor skill should be communicated via which media in which situation. Accordingly, ontology development for this domain should be subject to verification by those who will be responsible for the communication of skill knowledge.

5.3 Associating semantic representations

In addition to computational semantics research concerned with natural language, there has been some exploration of visual semantics. Fundamental research has included the development of semantic frameworks for visual languages (e.g. Erwig, 1998). Applied research has included enabling the automatic retrieval of images. Some of this applied research has sought to use the text captions that accompany images as a starting point for the automatic image retrieval (Srihari and Burhans, 1995). In doing so, such research has explored ways of integrating linguistic and visual information. Other research has focused upon using visual semantics within images (Jaimes et al., 2000). It has been argued that intelligent image retrieval systems can be developed and experimental tests have been carried out (Belkhatir et al., 2005). Further, methods of event-based semantics for image retrieval have been proposed (Pedrinaci, Moran, and Norton, 2006). These can be used, for example, to filter live video content (Bertini et al., 2004; Hornsby, 2004). Overall, it could be argued that much of the ground work necessary to enable the association of semantic representations during the real-time communication of psychomotor skill knowledge has already been carried out. The application of stochastic language models, for example, is not limited to natural language (Kanungo and Moa, 2001). However, it is important to note it may be possible to avoid at least some of the syntactic analyses and semantic analyses that are essential to associating semantic representations to natural language. This is because visual languages and visual content for real-time communication of psychomotor skills could have much less inherent ambiguity than natural language. Firstly, because such visual languages and visual content would have a much narrower scope than natural languages. Secondly, because visual languages and visual content can be engineered to achieve disambiguity before they are introduced for widespread use. Such engineering could be aided by cognitive architectures which are concerned with the modelling of human-machine systems (Kieras, 2004).

5.4 Drawing inferences from semantic representations

A primary inference in the real-time communication of skill knowledge would be in determining which skill information, in which format, to communicate initially. Another important inference would be in determining which information, in which format, to communicate as feedback. Here, the principles and practice of dialogue management in existing computational semantics applications are very relevant. Further important inferences would be in determining the each particular recipient's broader strengths and weaknesses in relation to relevant psychomotor skills. Here, the principles and practice of intelligent tutoring systems are particularly relevant. Moreover, computer-interpretable information models developed during the design of products could provide a relatively low cost opportunity for simplifying access to visual representations of psychomotor skill knowledge. Such models are known as, for example, product models (in manufacturing) and building information models (in construction). These models offer interactive three dimensional visualizations of products, buildings etc. Accordingly, they can be used to communicate what to do next and where to do it to people who lack basic skills (Mourgues et al., 2007). Figure 26 below shows the types of three dimensional visualization from building information models (BIMs). These examples illustrate the different levels of detail that can be viewed and the quality of visualizations which are available.

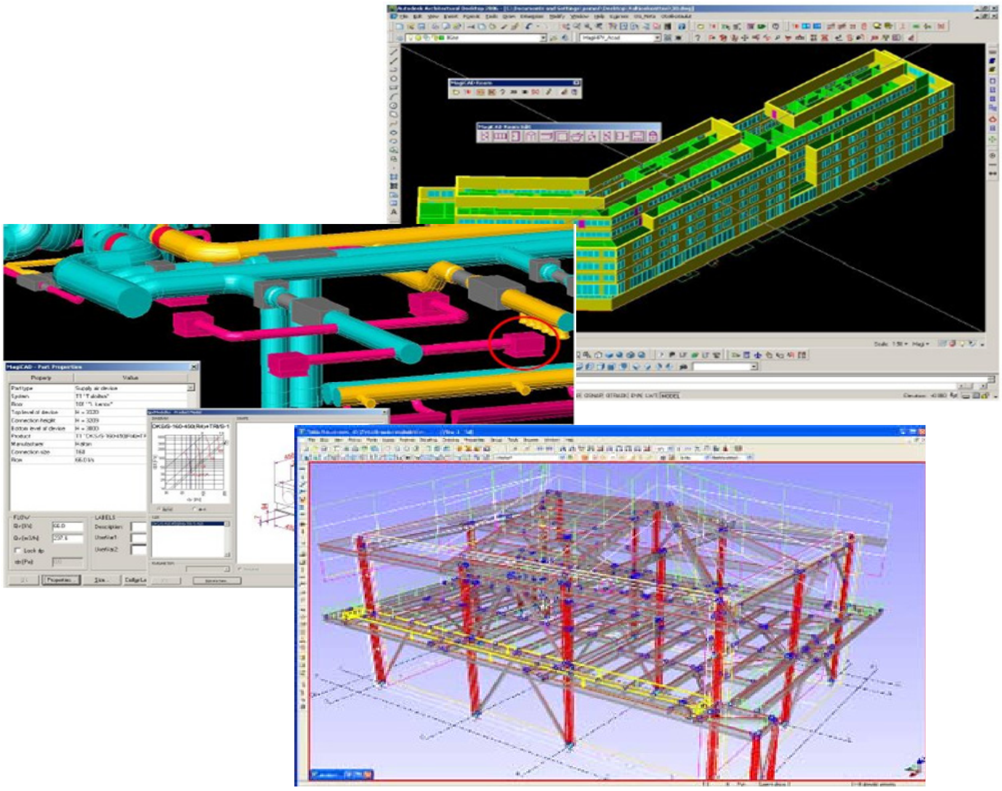


Figure 26. Examples of visualizations from BIMs. (Source: see page 83.)

Links to visual presentations of psychomotor skill knowledge, such as video footage, could be included in models. The links could be accessed via the digital object in three dimensional visualizations which depicts the part of the product, building etc., that skill information is need for. For example, by clicking on or touching the visualization of a pipe connection, a person could access the psychomotor skill information relevant to that connection. The annotation of visual skill information, such as video footage, with semantic tags could enable the automation of linking skill information to product models, BIMs etc. The degree of inference required could be much reduced by linking of visual skill information to appropriate digital objects in advance.

5.5 Communication processing devices

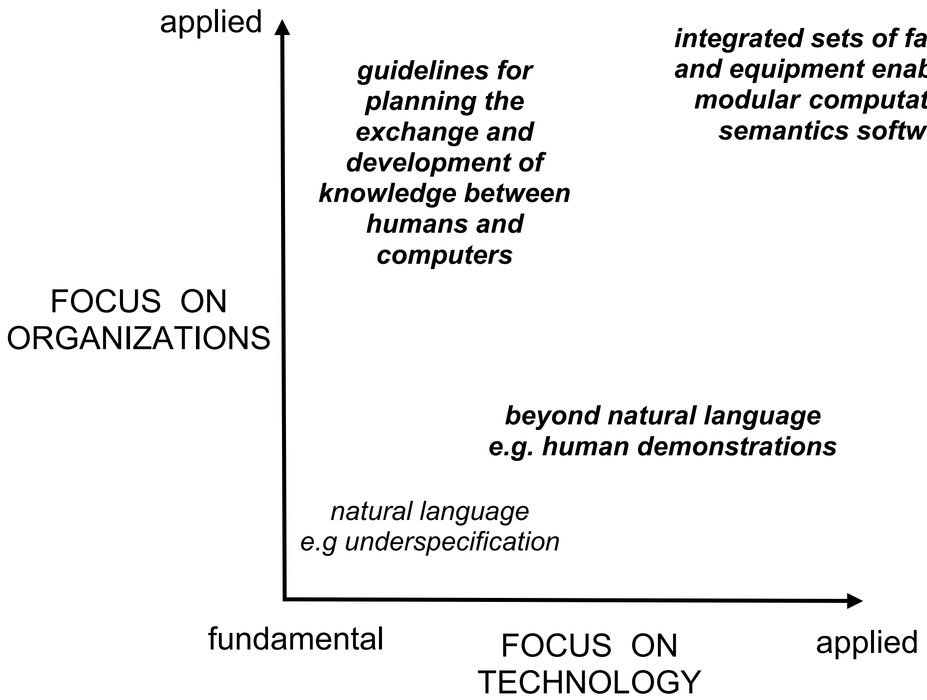
The operation of facilities and equipment for the real-time communication of psychomotor skills without the use of natural language could be enabled by computer-vision based human-computer interaction. This enables the control of facilities and equipment through the use of hand gestures. Computer-vision enable control can involve image capture, colour segmentation, feature detection, tracking and pose recognition and then application control (Bretzner et al., 2001). Further, computer vision-based human motion capture would be important for comparing “as-performed” psychomotor actions to “as-defined” psychomotor actions. Such comparisons are essential to the preparation of appropriate feedback. Human motion capture has been defined as the process of capturing large scale body movements, of a subject, at some resolution (Moeslund and Granum, 2001). Same scale body movements such as facial expressions and hand gestures are not included within this definition. There are three major existing application areas for human motion capture: surveillance, control and analysis. Surveillance covers applications where one or more subjects are being tracked over time and possibly monitored for special actions. A common example is the surveillance of a parking lot, where a system tracks subjects to evaluate whether they may be about to commit a crime such as stealing from a car. Control applications use captured motions to provide controlling functionalities in, for example, games and virtual environments. Analysis applications are used in, for example, clinical studies to analyse captured motion data and in doing so help athletes to understand and improve their performance. Active sensing has operated by placing devices on the subject and in the surroundings which transmit or receive generated signals respectively. Passive sensing is based on “natural” signal sources such as visual light or other electro magnetic wavelengths, and need no wearable devices.

5.6 Modular systems architectures

Modular systems architectures have enabled existing computational semantics applications to be developed by a variety of specialists working concurrently. Further, modular systems architectures have enabled the enhancement of existing components and addition of new components over time. Furthermore, plug-and-play modules which can reduce cost and increase flexibility are becoming available (e.g. Mirkovic and Cavedon, 2006). This approach will be beneficial for the continuous development of applications that enable the real-time communication of psychomotor skills. Not least, because of the range of specialist expertise and resources that will be needed in their development. The systems architectures of visual application prototypes and share many similarities with natural language applications (e.g. Soo et al., 2002).

5.7 Implications for computational semantics

The development of applications for the real-time communication of psychomotor skills to people without basic skills could have considerable implications for computational semantics. In particular, fundamental research could be expanded beyond natural language to include human demonstrations. Human demonstrations are a global form of communication that is directed towards the exchange, sharing and development of knowledge. For example, a human demonstration of how to use a hammer to knock a nail into a piece of wood is directed towards the sharing of human skill knowledge. In this case, and many others, a demonstration can be much more effective than a spoken and/or written natural language explanation. Figure 27 below provides a diagrammatic illustration of what might be the scope of computational semantics in the future. This diagram includes the new directions for both fundamental and applied research in computational semantics.



COMPUTATIONAL SEMANTICS – in the future?

Figure 27. Computational semantics – in the future?

This diagram includes guidelines for planning the exchange and development of knowledge between human beings and computers. Such guidelines are essential to reducing the amount of computation semantics expertise that would be needed in setting up integrated sets of facilities and equipment for the real-time communication of skill knowledge. Guidelines could encompass, for example, gesture-based operation of just-in-time intelligent training facilities for psychomotor skills. Further, guidelines could include rules for the development of company-specific visual language symbols for use in such human-computer interactions. Guidelines should provide information about how to simplify the annotation of visual information with semantic tags to enable automated processing such as linking to product models. Without generic guidelines, the potential number of computational semantics will be restricted by the limited number of people with relevant expertise. Integrated sets of facilities, such as tutoring stations, and equipment, such as augmented reality headsets, could carry forward the modelling of human understanding carried out with existing intelligent tutoring systems (ITS). Currently, intelligent tutoring systems create models of each individual trainee's strengths and weaknesses based on responses received from each trainee. Intelligent tutoring systems tailor their instruction based on those continually updated model. With the real-time communication of psychomotor skills, a model of each person's skill level developed during just-in-time training could be used to determine what amount and level of point-of-use skill information should be provided to each person as they undertake work tasks. Overall, the focus of computational semantics could shift from individuals, such as individual analysts or individual trainees, to entire organizations. This could happen if computational semantics applications are deployed by organizations to meet their general need to improve the skills of entire workforces rather than to improve the performance of selected individuals.

5.8 Section summary

The potential for applying computational semantics to the real-time communication of psychomotor skills has been discussed. Important topics are summarized below.

- An appropriate approach for the development of communicative ontology for real-time communication of skill knowledge may be to use cognitive architectures to model cases. Then, to relate those cases to existing communicative ontology in order to assess their relevance.
- Concepts relevant to the domain of real-time communication of psychomotor skills to people without basic skills include: psychomotor skills required by work task and work situation; existing level of psychomotor skill; level of natural language literacy; level of literacy in information and communications technologies (ICTs); fundamental capabilities of media. Overall, the various domain concepts are already quite well defined.
- Overall, it could be argued that much of the ground work necessary to enable the association of semantic representations during the real-time communication of psychomotor skill knowledge has already been carried out. The application of stochastic language models, for example, is not limited to natural language (Kanungo and Moa, 2001).

- A primary inference in the real-time communication of skill knowledge would be in determining which skill information, in which format, to communicate initially. Another important inference would be in determining which information, in which format, to communicate as feedback. Here, the principles and practice of dialogue management in existing computational semantics applications are very relevant. Further important inferences would be in determining the each particular recipient's broader strengths and weaknesses in relation to relevant psychomotor skills. Here, the principles and practice of intelligent tutoring systems are particularly relevant.
- The operation of facilities and equipment for the real-time communication of psychomotor skills without the use of natural language could be enabled by computer-vision based human-computer interaction. This enables the control of facilities and equipment through the use of hand gestures. Computer-vision enable control can involve image capture, colour segmentation, feature detection, tracking and pose recognition and then application control (Bretzner et al., 2000). Further, computer vision-based human motion capture would be important for comparing "as-performed" psychomotor actions to "as-defined" psychomotor actions.
- Modular systems architectures will be beneficial for the continuous development of applications that enable the real-time communication of psychomotor skills. Not least, because of the range of specialist expertise and resources that will be needed in their development. The systems architectures of visual application prototypes and share many similarities with natural language applications (e.g. Soo et al., 2002).

The development of applications for the real-time communication of psychomotor skills to people without basic skills could have considerable implications for computational semantics. In particular, fundamental research could be expanded beyond natural language to include human demonstrations. Overall, the focus of computational semantics could shift from individuals, such as individual analysts or individual trainees, to entire organizations.

6. Conclusion

The principal findings are listed below. Subsequently, directions for future research are outlined.

6.1 Principal findings

- The following factors are important to the instruction of psychomotor skills: task analysis; physical and mental practice; visual demonstrations and visual imagery; augmented feedback. There are many options for instruction of psychomotor skills without the use of natural language. Moreover, natural language may be a hindrance to the instruction of psychomotor skills.
- There have been many innovations which have some potential to enable the real-time communication of psychomotor skills to people who are lacking in basic skills. These innovations include technologies such as ambient intelligence, wearable computing, and methods such as just-in-time training, point-of-use information.
- Computational semantics is recognized as being an important enabler for innovations that have the potential to facilitate the real-time communication of psychomotor skills to people who lack basic skills.
- Computational semantics applications often involve typical systems analyses activities. There are a number of components that are common among computational semantics applications. These include: ontology; automated process of associating semantic representations; automated process of drawing inferences from semantic representations; communication processing devices.

6.2 Future research

- The development of communicative ontology and domain ontology will be essential. These development activities can be informed by the growing literature concerned with the development of ontology.

Experimental testing of the common phases of multiple analyses, semantic annotation, pragmatic inference, and machine control will be required and can be informed by existing work in the application of computational semantics to visual communication.

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Sources for figures that are not drawn by the lead author, or that are not cited in text, are listed below.

Figure 1: Studierstube Augmented Reality Project; VTT; MD&DI.
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Figure 6: Fascias.com; Cincinnatti.com
http://images.google.com/imgres?imgurl=http://www.master-plastics.co.uk/media/roof%2520lanterns/roof_lantern11.jpg&imgrefurl=http://www.fascias.com/en-gb/pg_65.html&h=225&w=300&sz=39&hl=fi&start=47&tbnid=8XTFeDXLPy4_6M:&tbnh=87&tbnw=116&prev=/images%3Fq%3Dglazing%2Bhammer%26start%3D40%26gbv%3D2%26ndsp%3D20%26svnum%3D10%26hl%3Dfi%26sa%3DN

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Figure 9: Beigl/Schmidt
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Figure 10: Columbia University Computer Graphics and User Interfaces Lab
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Figure 11: KAIST
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Figure 16: PCMag.com
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Figure 17: Fleet Week: Office of Naval Research Technology:
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Figure 18: Virtual Experiences Research Group University of Florida
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Figure 19: Stottler Henke
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Figure 20: Stottler Henke
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Figure 26: Tekla.com

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