

# Measurement of Articulate Tacit Knowledge using Formal Concept Analysis

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## Abstract

*This paper proposes a methodology aimed at mapping the diffusion of articulable tacit knowledge in an organisational context focusing specifically on computing personnel, based on research conducted so far by way of a pilot study. Articulate knowledge and its capture is commonplace, tacit knowledge has however until recent years proved elusive in its inclusion within the organisation's knowledge base. We chose to use a combination of psychology based testing to extract the Tacit Knowledge of computing personnel and Formal Concept Analysis as a tool to graph results from our initial testing. For our main study we foresee the additional use of Social Network Analysis as a means of determining how the flow of Tacit Knowledge is effected between personnel. Initial results would seem to indicate that our methodology is useful in mapping knowledge that does not lend itself easily to being articulated. Consequently we feel such knowledge capture will prove invaluable within the IS domain.*

## Keywords

AL01 Knowledge representation; AL04 Knowledge acquisition; AP Psychology; AI0801 Positivist perspective; DD07 Information flows; FC15 IS models; FC16 Interviewing; HB26 Simulation and modelling IS; Formal Concept Analysis; Social Network Analysis; Codified Knowledge; Tacit Knowledge; articulable Tacit Knowledge; Diffusion of knowledge

## INTRODUCTION

Articulate knowledge exemplifies essentially all forms of electronic and written documentation, tacit knowledge on the other hand: "..... is non – codified, disembodied know how that is acquired in the informal take – up of learned behaviour and procedures" (Howells 1995 :2). Indeed, it is Tacit Knowledge that provides the competitive edge to many an organisation (Zucker *et.al.* 1998; Johannessen *et.al.* 1997; Lei 1997; Howells 1995; Senker 1995; Sternberg *et.al.* 1995), and may well provide the basis for knowledge valuation differences between the private and public sectors. We should point out that much tacit knowledge is able to be articulated or made explicit given time, however a proportion remains tacit for largely practical and competitive-advantage related reasons. As such the researchers shall limit themselves to *articulable Tacit Knowledge (aTK)* or that proportion which is actually articulated, within this paper. What the authors essentially seek to do is 'map' diffusion of *aTK* within the Information Systems domain. Our reasons for doing so are primarily altruistic, as the transference of intra – organisational *aTK* would not only lead to increased organisational competitiveness, but more effectively enable the transfer of

productive hard to define 'know-how' (as opposed to 'know – that/what') to junior personnel who typically possess less of it than senior personnel as studies have shown (Sternberg *et.al.* 1995). Although we make use of language as a means to extract and convey information, much articulable Tacit Knowledge is also hidden in our thoughts and deeds which may nevertheless be able to be interpreted through the correct usage of tools. This 'capture' may aid in improved requirements gathering, systems development or management decision making. Underlying such benefits at the basic language level, our role as researchers is thus to ".... explicate the tacit knowledge of semiotics if it exists, [and] to develop new knowledge if it does not, and thereby to make the information generation – information dissipation – organisation cycle more effective and efficient" (Ramaprasad *et.al.* 1996 :192).

Although a great many researchers make mention of (*articulable*) Tacit Knowledge, we have largely only Sternberg's Yale University research group (Horvath *et.al.* 1999; 1999; Torff *et.al.* 1999; Wagner *et.al.* 1999; 1998a; 1998b; 1995; *et.al.* 1995; *et.al.* 1993; Wagner *et.al.* 1990; 1989; 1987; Wagner *et.al.* 1987; Wagner *et.al.* 1985;) to thank for having provided to date the most effective instrument for being able to measure tacit knowledge in general, and as a management potentiality test specifically (Wagner *et.al.* 1991a; Wagner *et.al.* 1991b).

## THE KNOWLEDGE HIERARCHY

Data 'consists of raw facts' and information 'facts .. [with] value beyond the value of facts themselves' (Stair 1996). A hierarchy of knowledge also exists ranging from *Tacit Knowledge* (thoughts, deeds, skills, techniques, 'know – how', 'know - why', 'not knowing what we know'), through to *articulable Tacit Knowledge* (an unknown subset of the former that is eventually codified e.g. etiquette sets), through to *Articulated Knowledge* (all manner of print and electronic media), then on to *Codified Knowledge* (e.g. classification systems) and finally *Formalised Knowledge* (e.g. mathematical formulae and models) (Busch and Dampney 2000(b): work in progress). How then may one define Tacit knowledge and more specifically articulable Tacit Knowledge? Polanyi (1966) states "*we can know more than we can tell .... We know a person's face, and can recognise it among a thousand, indeed among a million. Yet we usually cannot tell how we recognise a face we know. So most of this knowledge cannot be put into words*" (:4). Other definitions also exist, Horvath (*et.al.* in press in Sternberg *et.al.* 1995) considers it to be "action oriented knowledge, acquired without direct help from others, that allows individuals to achieve goals they personally value" (:916). Sternberg (*et.al.* 1995) consider tacit knowledge to comprise the following attributes:

*First*, tacit knowledge is procedural in nature. *Second*, tacit knowledge is relevant to the attainment of goals people value. *Third*, tacit knowledge is acquired with little help from others. Knowledge containing these three properties is called tacit because it often must be inferred from actions or statements. .... the intention or content of the tacit knowledge concept is not fully captured by the meaning of the lexical item *tacit*. Tacit knowledge is typically implied rather than stated explicitly – but there is more to the tacit knowledge concept than this most salient feature (:916 italics added).

We choose thus to define *articulable Tacit Knowledge* as the set of actions and experiences that through careful usage of tools and methodologies may *largely* be expressed and transferred from one individual to the next.

## A MODEL OF TACIT KNOWLEDGE AT THE INDIVIDUAL LEVEL

In earlier work a model was developed (Figure 1 shown below; Busch and Dampney 2000), which displays the relationship of individual articulable Tacit Knowledge over one's career. The dashed spiral represents the *Articulate Knowledge* (AK) learning 'adoption' of the individual over a career lifetime, significant when first employed, gradually becoming less so as one becomes more senior within the organisation. The solid spiral represents *aTK*, which is minimal as the 'apprentice' enters the workforce, and is likely to increase significantly over the years. In fact it is probable that the pattern is not likely to be an outward branching spiral, but rather a waveform like spiral that will continually oscillate with an individual's career. We have shown in Figure 1, and this is supported by significant evidence (Wagner *et.al.* 1985; Sternberg *et.al.* 1995), that senior/more experienced people tend to score 'higher' on an *aTK* scale, while making less use of more formalised rule sets, algorithms or procedures (Polya 1973, Michener 1978, Soloway *et. al.* 1982, Scriber 1983 in Wagner *et. al.* 1985).

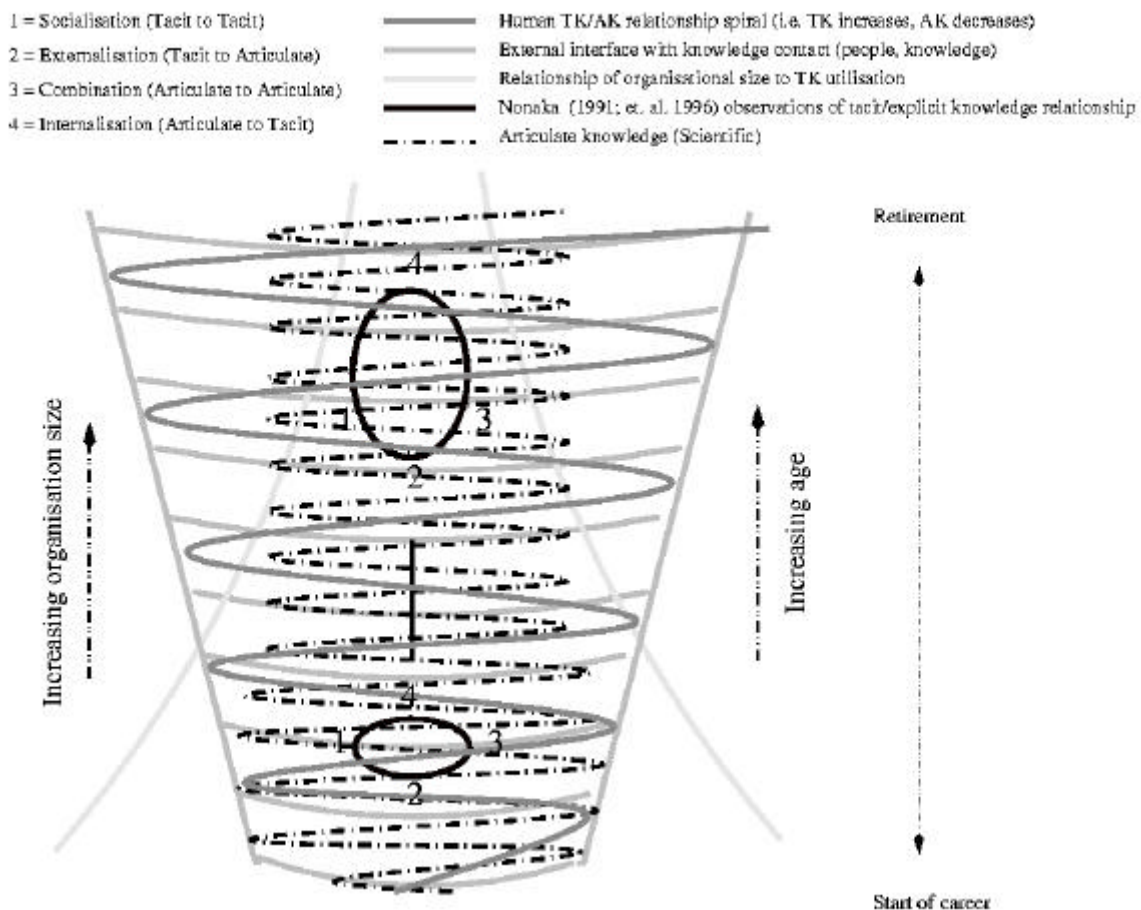


Figure 1: Tacit knowledge and the individual (source: Busch and Dampney 2000)

The outer 'cone' represents the external interface with which an individual interacts with 'knowledge' or 'people'. Overwhelmingly access to most forms of knowledge stems from AK which is typically represented by traditional written forms of information. The inner 'volume' of the cone represents the individual for whom AK and *aTK* is 'stored' over time, and able to be transferred to other individuals. The external surface of the cone represents contact with 'reality' or the outside world, based on the individual's *Weltanschauung*. The lightest grey lines serve to indicate the relationship between *aTK* and the size of an organisation. It has been noted (Caves *et.al.* 1976 and Imai 1980 in Hedlund 1994), that Japanese firms as an

example are generally smaller than western ones and that this is likely to influence *aTK* adoption. We hypothesise that the smaller the IS organisation, the more likely it is proportionately to make use of *aTK*. Finally the 'ring's represent work Nonaka (1991) and Nonaka, Takeuchi and Umemoto (1996) have undertaken into the relationship between TK and AK. In essence, 4 stages have been identified (Figure 2):

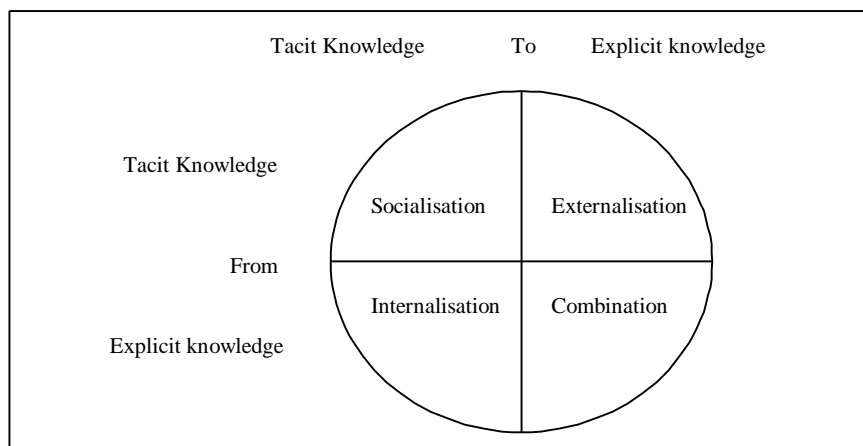


Figure 2: Four modes of knowledge conversion (modified from Nonaka, Takeuchi and Umemoto 1996 :835).

We consider that the cycle may typically be acyclic (Figure 1), particularly in later working life as senior personnel come to rely further on *aTK*, more so than AK. As knowledge researchers we are particularly interested in the externalisation or tacit  $\Rightarrow$  explicit stage.

## METHODOLOGY

A great deal of literature commencing with works by Polanyi (1958; 1966), has established the notion of *Tacit Knowledge*. However there is little known about the actual ability to extract this phenomenon, therefore our research aims to map *aTK* within the IS domain. As a means of increasing rigour associated with our research we feel it beneficial to adopt a triangulated approach (Jick 1983 in Scott 1990) which will incorporate; (a) Sternberg based psychological testing instruments; (b) Social Network Analysis as a tool to track knowledge dissipation, and; (c) Formal Concept Analysis as a means to balance results with those achieved by way of (a) Sternberg's method, and the dissipation (through personnel) of *aTK* viewed by way of (b) SNA. Our pilot study questionnaire and analysis utilised (a) and (c), while (b) will also be incorporated within our main study questionnaire

### Step 0: Interviews

Interviews were conducted as part of a pilot study with 12 computing related personnel of varying degrees of IT experience. IT personnel were chosen on the basis of their 'front office' and 'back office' experience to provide a cross section of the computing domain. We define 'front office' as being IS personnel who liase with external clients of the company, roles which include Data Architect, Business Analyst, Directors of firms, Consultants, Chief Information Officers. While 'back office' roles comprise Data Base Administrators, Programmers, Operators, Network personnel and Technical Analysts, namely those that liase with 'equipment' or 'internal' rather than 'external personnel'. Identities of individuals were kept confidential. Interviews were administered on the basis of asking individuals about tasks that progressed well and poorly and who within the organisation (without names) could be considered proficient at their tasks, those not so and why. In gaining such information, scenarios could then be constructed along the lines of Sternberg (*et.al* 1995).

## Step 1: Psychology based testing

Although to date a great deal of literature exists on the phenomenon of *aTK* in the workplace (Johannessen, *et.al.* 1997; Lei 1997; Nonaka 1991; *et.al.* 1996; Raghuram 1996; Zucker *et.al.* 1998), there is little in the way of methodology available for measurement of *aTK* other than that proposed by Sternberg (*et.al.* 1993; 1995; 1997; 1998a; 1998b; 1999); and his Yale University research group. The Yale approach makes use of a Likert scale for a sequence of scenarios for which respondents are asked to pick a rating. An alternative approach is for individuals to write 'plans of action' for how they would handle each of a series of complex problem situations (Williams *et.al.* in Sternberg *et.al.* 1995). Descriptive statistics along academic psychology lines then permit conclusions to be drawn as to the *aTK* inherent in individuals. Such an approach is methodologically individualistic, insofar as testing is done at the individual level with a view to generalising statistically upwards and outwards, as there appears to be even less in the way of methodology at the present stage that would enable the testing of *aTK* at a holistic organisational level. Our approach was to devise a similar test to the former approach (Figure 3), focusing on IS scenarios.

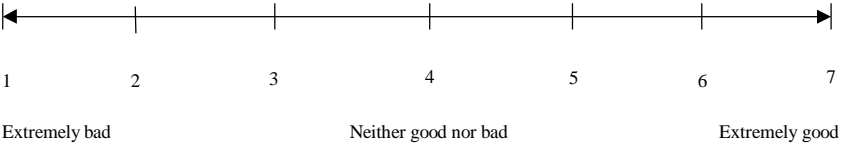
<b>Rate the following points on a 1 - 7 point scale</b>						
						
1	2	3	4	5	6	7
Extremely bad		Neither good nor bad		Extremely good		
<b>Scenario 1</b>						
<p>You have been assigned to a team of 6 people to work on a new database system for NSW Health. This system is somewhat contentious as it will involve accessing private information on clients, nevertheless you feel that the system will favourably capture 'management reporting' information, even if privacy may be impinged upon. Nevertheless the security policies and safeguards within the organisation are felt by you to be secure enough. Although you are new to the organisation, your previous work experience is respected and you realise that there are other jobs 'out there' should you decide 'create waves'. Within this team you are second in charge. How do you handle this situation? Do you:</p>						
<ol style="list-style-type: none"><li>1. Assign someone else to the team in your place and hope that the problem will eventually go away</li><li>2. Fully agree to the implementation of the system in the hope that the boss will notice your enthusiasm, thereby hopefully gaining you a promotion in years to come</li><li>3. Sabotage the implementation of the system, not necessarily physically but by allowing certain documentation to accidentally get 'mislaidd'</li><li>4. Find that all of a sudden your diary is very full and you are unable to participate in the project because of this upcoming paper you had suddenly thought of, that you need to be giving at a conference in the Singapore next month</li><li>5. Threaten to 'blow the whistle' on the project because you are concerned about ethical considerations</li></ol>						

Figure 3: A sample scenario used in the pilot study

## Step 2: Social Network Analysis

In a study of nursing interaction (Scott 1990; 1992), a triangulated methodology used participant observation to provide balance to the methodology proposed by Sternberg's group. Given the tendency of IS work to be undertaken at a monitor where body language and otherwise obvious workplace activities are minimised, we consider a more appropriate technique for our main study (as this has not been incorporated into our pilot study), to be the application of Social Network Analysis (Wasserman *et.al.* 1994; Koehly *et.al.* 1998; Paxton *et.al.* 1999), which will be used to ascertain how *aTK* is conveyed from one individual to another. Our SNA questions will be included within our main *aTK* inventory questionnaire so that we may ascertain with whom personnel in organisations are experiencing positive and

negative working relationships. We would expect for instance, that a negative working relationship is likely to diminish the transfer of *aTK*, and a positive relationship enhancing transference.

### Step 3: Formal Concept Analysis

A further means of providing balance in relation to tacit knowledge testing is that of modelling and comparing the results of Sternberg's approach by using a set-theoretic technique known as Formal Concept Analysis (FCA) (Wille 1982; 1997). FCA views a concept as being comprised of a set of objects: (G)egenstande, and a set of attributes: (M)erkmale, and the relationship between them: (I). A binary K(ontext) may be formally expressed thus:

$$K := (G, M, I)$$

A multivalued context may be expressed a quadruple:

$$K := (G, M, W, I) \text{ and } I \subseteq G \times M \times W$$

Where the relationship I is a subset of the combined components of Objects (G), Attributes (M) and merksmaleWerte (W) (Attribute-values).

We may interpret the responses to the Sternberg-style scenario as a formal context, a cross table, which can be constructed thus:

K = Formal table with its corresponding data	G = The participant
M = The responses	W = The value of the response
I = Relationship between the responses, their values and the participants	

Using the notion of a galois connection, formal concepts are found by determining the set of attributes shared by a set of objects or conversely the set of objects which share a set of attributes. More formally, the derivation operators:

$$X \subseteq G : X \mapsto X' := \{m \in M \mid gIm \text{ for all } g \in X\} \quad (\text{Formula 1})$$

$$Y \subseteq M : Y \mapsto Y' := \{g \in G \mid gIm \text{ for all } m \in Y\} \quad (\text{Formula 2})$$

are used to construct all formal concepts of a formal context, by finding the pairs  $(X'', X')$  and  $(Y', Y'')$ . We can obtain all extents  $X'$  by determining all row-intents  $\{g\}'$  with  $g \in G$  and then finding all their intersections. Alternatively  $Y'$  can be obtained by determining all column-extents  $\{m\}'$  with  $m \in M$  and then finding all their intersections. This is specified as:

$$X' = \bigcap_{g \in X} \{g\}' \quad (\text{Formula 3})$$

$$Y' = \bigcap_{m \in Y} \{m\}' \quad (\text{Formula 4})$$

Having found the set of formal concepts we can order these using the subsumption relation  $\geq$  on the set of all concepts formed such that  $(X_1, Y_1) \leq (X_2, Y_2)$  iff  $X_1 \subseteq X_2$ . By finding the predecessors and successors of each concept we can produce a visualisation of the concepts as a complete lattice, as shown in Figure 4 illustrating results from our pilot study. For a family

$(X_i, Y_i)$  of formal concepts of  $K$  the greatest subconcept, the join, and the smallest superconcept, the meet, are respectively given by:

$$\bigvee_{i \in I} (X_i, B_i) := ((\bigcup_{i \in I} A_i), \bigcap_{i \in I} B_i) \quad (\text{Formula 5})$$

$$\bigwedge_{i \in I} (X_i, B_i) := (\bigcap_{i \in I} A_i, (\bigcup_{i \in I} B_i)) \quad (\text{Formula 6})$$

Kollewe (1989) had also used survey data to construct a formal context but he treated the data of the table as the context ( $K$ ), the units of questioning as the objects ( $G$ ), the questions as the attributes ( $M$ ) and the answers to the questions as the attribute-values ( $W$ ). In our pilot study (Richards and Busch 2000), we chose to represent the data differently as it seemed more intuitive. We regarded the participant as the object ( $G$ ) that has a number of features ( $M$ ) such as age and position in addition to a set of responses and their values. This approach made data entry and validation easier as there was a one-to-one correspondence between the survey returned and the participant.

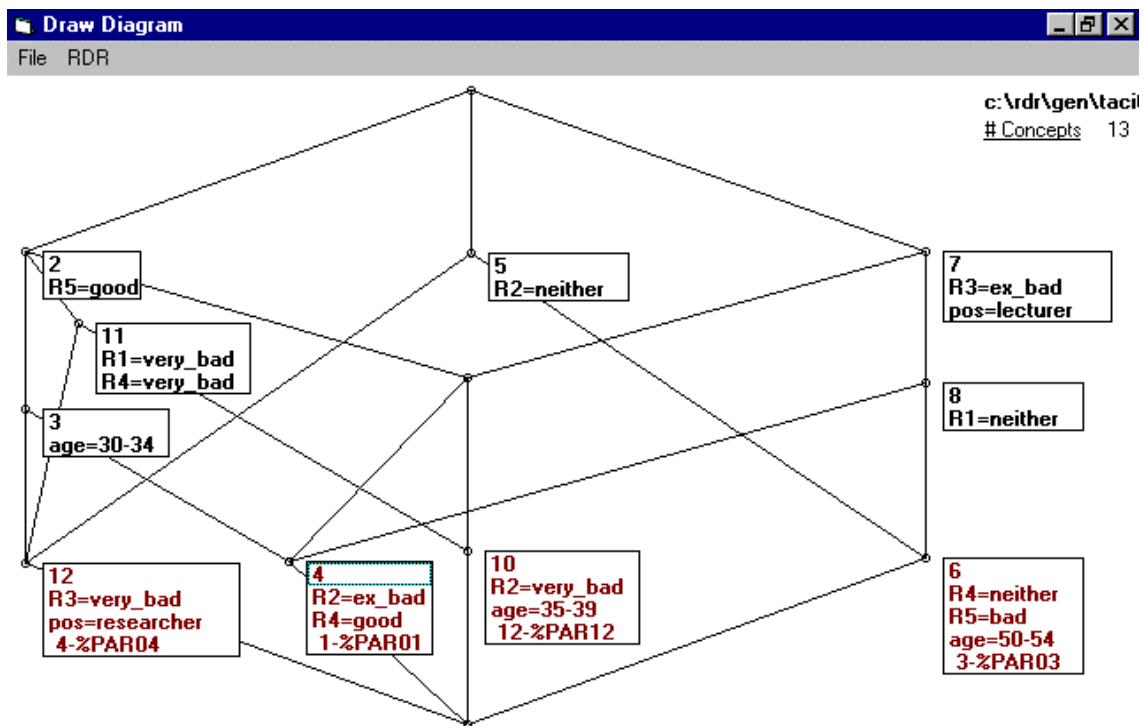


Figure 4: The concept matrix for all participants who share more than 1 response with participant 1 based on results from the pilot study.

The data used for modelling in our main study will be based on Sternberg scenarios and Likert scales. Some scenarios will also be presented in crosstable format. Our motivation is twofold. Firstly, we are interested to see whether the answers given by respondents to a scenario differ when asked to provide answers in alternative formats. If answers are consistent this will add rigour to our results. Secondly, we want to avoid biasing the data we use for modelling which could occur if we solely apply our own interpretation of the data from Step 1. Once we have the data in a crosstable we are able to automatically generate formal concepts by finding intersections of attributes and objects that share them, and display them as a complete lattice as shown in Figure 4. Although there are 49 concepts in the crosstable representing our pilot results in Appendix 1 (48 shown, as no respondent was between 60 – 64 years of age), this crosstable is only representative of a slice of the complete crosstable which would include over 180 primitive concepts (12 scenarios  $\times$  10 – 20 answer options per

scenario + biographical information), which would in turn be multiplied by potentially 200 respondents spread over several organisations. For the pilot study we have used a tool of our own design, known as MCRDR/FCA, to restrict the context so that the number of concepts may comprehensibly be displayed on a typical computer screen. In this instance our small pilot with 14 participants used the scenario given in this paper (Figure 3). The crosstable in Appendix 1 tabulates our results. The concept lattice of Figure 4 includes participants who shared two or more responses with participant 1, that is, participants 3, 4, and 12. The concept lattice in Figure 5 compares the responses of participants 1 and 3.

Concepts in Figures 4 and 5 are shown as small circles. Labels are attached to the right of the circle. Labelling has been reduced for clarity. Remember in FCA that a concept is a set of attributes and the set of objects that share them. The set of attributes that belong to a concept are reached by ascending paths and the objects that belong to a concept are reached by descending paths. Thus in Figure 4, concept number 11 includes the attributes (or in our usage the participant's choices and features) {S1=Extremely\_bad, S4=Neither\_good\_nor\_bad, S5=good}, and the objects (the participants as identified by the rule number and the conclusion code which begins with %) {Participant 4, Participant 12}. While these two participants made the same choice for responses 1, 4 and 5 to scenario 1, they differ in their positions held, their ages and choices to responses 2 and 3. We can also see that participant 3 is the least similar to the other participants, as he/she has 3 attributes that are not shared with anyone else (concept number 6). Figure 5 details how Participant 1 and 3 are similar and dissimilar. Concept number 1, the top concept shows that both participants share the same position and choices to response 1 and 3. Concepts number 2 and 3 show the differences between the two participants.

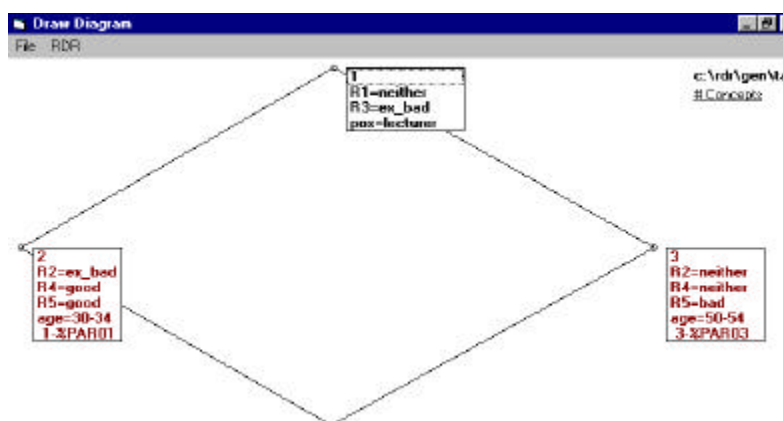


Figure 5: The Concept Lattice for Participant's 1 and 3.

## CONCLUSION

We anticipate that the structure and patterns that appear in the concept lattice, together with the results using Sternberg's measurements, will enable us to determine a number of questions: 1. To what extent *aTK* exists in the IS domain within an organisation; 2. How closely *aTK* measured by way of the Sternberg approach matches with that of Formal Concept Analysis and the various strengths of both approaches; 3. What features differentiate IS individuals who have accumulated more *aTK* from those with significantly less *aTK*; 4. Some insights into how *aTK* may be made explicit and passed on to those with less *aTK*; 5. Also eventually, how our technique might be extrapolated towards testing for holistic organisational as opposed to simply personal, *articulable Tacit Knowledge*.



In summary, our primary tool will be to use a Sternberg approach to *aTK* measurement, and secondly to balance these findings with those of another quantitative methodology, namely Formal Concept Analysis, thirdly making use of Social Network Theory as a means of measuring the 'flow' of *aTK* from one individual to the next. The aim of this paper has been to present a research approach into the externalisation of *aTK*, focused particularly within the Information Systems domain. We have also presented some of our micromethodology and given an example of a Sternberg-style scenario and some data captured in a small pilot study, which we have formalised and modelled using FCA. We are currently analysing the interviews (from Step 0) to develop scenarios and corresponding crosstables for our complete study, which will be conducted in the near future. This will seek to determine whether there are differing levels of *aTK* between 'front office' and 'back office' roles. Secondly this may test whether, given the competitive nature of *aTK* and indeed just TK, the private sector retains staff with a higher concentration of such knowledge, versus the public sector for whom interorganisational competition is less intense given their essentially monopolistic missions.

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## APPENDIX 1 (PILOT STUDY RESULTS)

Subject topic	No.	Question meaning	Response options	Participants responses													
				P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
Privacy and management reporting	1	Personnel assignment	Extremely good														
			Very good														
			Good														
			Neither good nor bad	X		X						X		X			
			Bad					X								X	X
			Very Bad		X		X				X				X		
			Extremely bad						X	X			X				
	2	Boss notice	Extremely good						X								
			Very good														
			Good									X					
			Neither good nor bad		X	X	X							X			
			Bad														X
			Very Bad					X		X			X		X	X	
			Extremely bad	X							X						
	3.	Sabotage	Extremely good														
			Very good														
			Good														
			Neither good nor bad														
			Bad														X
			Very Bad					X		X			X	X	X	X	
			Extremely bad	X	X	X			X	X	X				X		
	4.	Full diary	Extremely good														
			Very good														
			Good	X													
			Neither good nor bad			X								X			
			Bad									X					X
			Very Bad		X		X	X		X			X		X		
			Extremely bad						X		X					X	
	5.	Blow whistle	Extremely good											X			
			Very good													X	
			Good	X			X								X		X
			Neither good nor bad					X									
			Bad			X				X		X					
			Very Bad		X						X		X				
			Extremely bad						X								
Occupn			Lecturer	X		X			X	X			X	X	X		X
			Consultant													X	
			Researcher				X										
			Tutor					X									
			Computer Support		X						X	X					
Age			20 – 24									X					X
			25 – 29					X		X							
			30 – 34	X			X										
			35 – 39						X						X		
			40 – 44		X											X	
			45 – 49								X						
			50 – 54			X											
			55 – 59										X	X			

Primary concept table derived from the pilot tacit knowledge scenario

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