Exploratory Steps Toward Formal Analysis Methods for Knowledge Networks, A Socio Technical Perspective

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Modelling and Analysis of Networked and Distributed Systems
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http://www.cs.stir.ac.uk/events/network-analysis/
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• WORK AHEAD
Knowledge Networks for Systems Engineering are here considered as STS. In this presentation I attempt to:

- Identify the problem space
- Capture and characterise some of the key factors
- Justify the requirement for formal analysis
- Evaluate Options
- Point to work ahead

LIMITATIONS:
Still exploratory, in progress
MAIN QUESTION
(for this presentation)

What formal methods are adequate for the modelling and analysis of knowledge driven socio technical networks?
DEFINITIONS

FORMAL METHOD: mathematical /Logical technique for the specification, development and verification of systems.

KNOWLEDGE: cognitive ability to interpret, understand and apply information and data, and their correlations (and what we have not enough of, as opposed to data and information of which we get saturated with), human characteristic

Note: K is the product of emergence, and a dynamic, adaptive cognitive state (to be 'in the know')

SYSTEM: “a complex whole” formed from a “set of connected things or parts” (Allen, 1984)

STS: System resulting from the interaction of social and technical systems

KNOWLEDGE NETWORK: Network for transmitting information within an organization that is based on informal contacts between managers within an enterprise and on distributed information systems.

highered.mcgraw-hill.com/sites/0073381349/student_view0/glossary.html
A Framework for Formal Analysis

Introduction:
- A framework for formal analysis and abstract modelling.
- Languages, methods, tools.
- Solid logical foundations: carefully articulated philosophical rationale.

Methods
- Supporting reliable deductive reasoning with abstract models in all application domains

Philosophy
- Epistemology, phil. logic, mathematics and engineering underpin the framework.
- Varieties of philosophical analysis are considered, a new one is presented.

History
- Varieties of 20thC philosophical analysis are contrasted with the formal analysis advocated here

Epistemology
- Familiar fundamental epistemological distinctions are identified on which formal analysis is predicated

Logic
- An analysis of the nature of logical truth leads to firm logical foundations for formal analysis
- The logicist thesis is reaffirmed and related to other positions in mathematical philosophy

Engineering
- A formal analytic position is elaborated on the application of logic through mathematics in science and engineering

Philosophy
- Applications of formal analysis in philosophy are considered

Logic:
- Single powerful classical logical foundation system provides a touchstone for analytic truth.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Pedigree</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>modern predicate calculus</td>
<td>Frege</td>
<td>expressive for mathematics</td>
</tr>
<tr>
<td>the iterative conception of set</td>
<td>Cantor</td>
<td>clean semantic bedrock</td>
</tr>
<tr>
<td>logical type theory</td>
<td>Russell</td>
<td>consistency and discipline</td>
</tr>
<tr>
<td>axiomatic set theory with separation</td>
<td>Zermelo</td>
<td>consistency and flexibility</td>
</tr>
<tr>
<td>simply typed lambda-calculus</td>
<td>Church</td>
<td>uniform variable binding</td>
</tr>
<tr>
<td>replacement axiom for sets</td>
<td>Fraenkel</td>
<td>logical strength in set theory</td>
</tr>
<tr>
<td>simple polymorphism</td>
<td>Milner</td>
<td>more flexible type system</td>
</tr>
</tbody>
</table>

Gordon's polymorphic Higher Order Logic, and a classical set theory with universes and polymorphic urelements, provide a strong, conservative, pragmatic, implementable logical foundation for the field of analysis.
SOCIO TECHNICAL SYSTEM

CONSTANT CHANGE/EVOLUTION
CAUSAL DEPENDENCIES
INTERACTIONS AND TRANSFORMATIONS
PSYCHOLOGICAL AND SOCIAL FACTORS
<table>
<thead>
<tr>
<th>Illustration</th>
<th>Production Network</th>
<th>Development network</th>
<th>Innovation Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of the system</td>
<td>Mechanical</td>
<td>Organic</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Aim</td>
<td>Effective production of a pre-designed product for the focal company</td>
<td>Sharing knowledge between actors. Shared knowledge benefits the actors individually</td>
<td>Constant creation of innovations and new knowledge</td>
</tr>
<tr>
<td>Structure</td>
<td>Vertical</td>
<td>Horizontal</td>
<td>Diagonal</td>
</tr>
<tr>
<td>Relationships</td>
<td>Determined by hierarchy</td>
<td>Reciprocal, seeking consensus</td>
<td>Spontaneous, abundant</td>
</tr>
<tr>
<td>Social connections in the network type</td>
<td>Not many. Interaction is restricted to production-related matters</td>
<td>Every organization (actor) is represented by a person. These representatives keep up personal relations with each other</td>
<td>There are a lot of connections between the firms’ personnel</td>
</tr>
<tr>
<td>Duration of co-operation</td>
<td>Long-term. Dyadic relations are important investments</td>
<td>Can be either long-term or short term</td>
<td>Co-operation sustained until innovation is complete</td>
</tr>
<tr>
<td>Knowledge and competence</td>
<td>Defined, explicit</td>
<td>Experiential, hidden, tacit</td>
<td>Intuitive, potential</td>
</tr>
<tr>
<td>Information flow</td>
<td>One-way, top-down</td>
<td>Multi-way, horizontal</td>
<td>Chaotic, sporadic</td>
</tr>
<tr>
<td>The role of communication in the network</td>
<td>Clear rules and regulations. Possibly a shared ERP system</td>
<td>Casual interaction between people in a specific region</td>
<td>A lot of entropy, i.e. excess communication and information</td>
</tr>
<tr>
<td>Importance of location</td>
<td>Subcontractors can be located geographically anywhere as long as logistics and information flows are functioning</td>
<td>Requires face-to-face communication</td>
<td>Regionality is pronounced in the development of innovations, but some actors can still be located geographically elsewhere</td>
</tr>
<tr>
<td>Management and leadership method</td>
<td>Orders, direct use of power</td>
<td>Dialogue, empowerment</td>
<td>Personal networking skills, relinquishing power</td>
</tr>
</tbody>
</table>
A technological system is defined as:

... networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse and utilize technology. Technological systems are defined in terms of knowledge or competence flows rather than flows of ordinary goods and services.

.....They consist of **dynamic knowledge and competence networks** (Carlsson and Stankiewicz, 1991).....

.....The material aspect of systems is central in the **Large Technical Systems (LTS)** approach. technology involving infrastructures, e.g. electricity networks, railroad networks, telephone systems, videotex, internet.....

(FROM: http://www.ksinetwork.nl/downs/output/publications/ART029.pdf)
Knowledge Networks for Systems Engineering

MAIN ISSUES:

• K is essential to critical decisions, which rests on humans
• Engineers are familiar with data and information, rather than 'knowledge'
• SEEngineering BOK is a challenge for the practice (they tend to have a components engineering perspective)
• Knowledge exchange is limited
• Knowledge Management is a challenge for the practice
KNOWLEDGE ENGINEERING

- Knowledge is essential factor to
- innovate
- ensure dependability
- decision making at all levels
- Knowledge Management Requirements are increasing
- Knowledge Networks are essential to satisfy these requirements
MORE GENERAL K CHALLENGES

- Information overload
- Exponential Increase of knowledge requirements
- Very fast knowledge exchanges
- Very fast systems development cycles
- Can't keep up with progress in different areas
- Convergence of many disciplines
- Difficult to stay on top of everything
- Too much knowledge to grasp/reason with/model/represent
- Very rapid changes, short iterations make project planning difficult
PROBLEMS CAUSED BY LACK OF K

- Limited ability to make decisions!
- Systems which can be theoretically perfect, but that in practice display various classes of flaws
- Error/Accident/Risks that derive
- General lack of awareness
- In commercial terms: no ability to innovate, general cluelessness, no 'edge'
- Sometimes unintelligent outcomes
- All/most problems caused by inadequate K
KNOWLEDGE DISCONNECTEDNESS

Working Definition: when knowledge about a fact, or set of facts is fragmented, and is not accessible as a whole, results in 'very few know something', K is often mistaken for belief, opinion, or awareness of something (do you know ?...)

an old metaphor of the elephant and the blind men

image source: mcckc.edu/~lewis/gs/blindmen.htm
MORE SPECIFIC PROBLEMS

• Despite mission critical, fault tolerant, zero tolerance systems, systems fail sometimes with fatal consequences
• Human factors, more specifically the poor modelling of socio technical factors is identified as a key contributing factor
KD COMPLEX PROBLEM

MADE UP OF DIFFERENT PROBLEM SPACES:
TECHNICAL
COGNITIVE
ORGANISATIONAL
SOME ARE POLICY

BUT MOST PROBLEMS ARE COMPOUND
(problem entanglement)
PROBLEM CHAIN/DEPENDENCIES

(DOCTORAL RESEARCH / A FRAMEWORK)
JUSTIFICATION: THE NEED FOR FORMAL ANALYSIS IN STS

Seven Principles of Sociotechnical Systems Engineering ...
Development methods must support formal analysis for dependability. Sociotechnical - Martyn Tomas

1. Preserve the real world requirements
2. Keep the humans in the loop
3. Training is a first-class system component
4. Human behaviour must be made dependable
5. Don’t set traps
6. Plan for deviant behaviour
7. Development methods must support formal analysis for dependability

www.indeedproject.ac.uk/wstse/programme/.../thomas08principles.ppt
Keep the humans in the loop
   “why is it doing that?”
All humans within the STS must understand the system’s behaviour adequately at all times.

The system designer should ensure that the users understand what the system is doing

14 February 1990; Indian Airlines A320; Bangalore, India: Controlled flight into terrain during approach. Aircraft hit about 400 metres short of the runway. Four of the seven crew members and 88 of the 139 passengers were killed. The pilot had accidentally caused the A320 to enter “Open Idle descent”. This had the effect of delaying “alpha-floor activation” which the PIC probably thought would save them. [See Mellor 1994]
Development methods must support formal analysis for dependability

- It is impractical or impossible to gain adequate confidence in any significant STS through testing alone.
- Formal analysis must therefore be at the core of the dependability case.
- The necessary science is incomplete. The engineering methods that exploit the science are immature or have not yet been developed.
- Current industry standards for developing critical STS are inadequate.
- This is a grand challenge for researchers and for the systems industry.
CASE: Uberlingen =From the PAPER Causal Analysis of the ACAS/TCAS Sociotechnical System

1 July, 2002, a Tupolev 154M operated by Bakshirian Airlines (BTC), a Russian airline, was flying Southern Germany destination in Catalunya. A Boeing 757 operated by the cargo airline DHL was ying northbound over Switzerland Both were operating under Instrument Flight Rules (IFR), compulsory at this Flight Level.

Skyguide, the Swiss air trac control organisation, had control of both aircraft, and accordingly responsibility for separation of the aircraft. controller on duty operating two positions, some meters apart, because colleagues were on break. Another air trac control facility at Karlsruhe had noticed the convergence, but was unable to contact Zurich through the dedicated communication channel, which was undergoing maintenance 11 seconds after DHL informed the controller of the TCAS descent, the two aircraft collided. (sad twist: controller involved was murdered by presumed distraught relative of an accident victim)
Uberlingen collision
The responsible investigating authority, the German BFU, issued report in May 2004 [Bun04]. It contains a thorough discussion of the sociotechnical system consisting of the Skyguide air traffic control

- Many factors contributing to the accident concern the operation of this system. In addition, BTC's decision to descend was cited as a factor. The TCAS avionics was found to have operated as designed and intended.
- Also cited as a factor were the many, often contradictory, procedural instructions or advice to pilots on appropriate procedures on reception of a TCAS Resolution Advisory. The report enumerates all these pieces of advice and contains a thorough discussion.
- **BOTTOM LINE:** given the contradictory mess, the only possible decision rests on the cognitive state of the person in charg (uh?)
FA FOR STS ARE MUCH NEEDED

Formal Analysis Methods (as we know them) do not take into account human/cognitive/social norms factors. Adequate Methods need to be developed. We can draw from existing practices, for example: Morphological Analysis.
Morphological Analysis

- From classical Greek (morphè) :and means shape or form
- Morphology is the study of the shape and arrangement of parts of an object, and how these parts "conform" to create a whole or Gestalt.
- The "objects" in question can be physical objects (e.g. an organism, an anatomy, a geography or an ecology) or mental objects (e.g. word forms, concepts or systems of ideas).

A methodological framework for creating models of systems and processes, which cannot be meaningfully quantified

- Extended typology analysis was invented as early as the 1930's by Fritz Zwicky, professor of astronomy at the California Institute of Technology – the famous Caltech in Pasadena
MORPHOLOGICAL ANALYSIS IS:
A GENERALISED METHOD FOR STRUCTURING AND ANALYSING COMPLEX PROBLEM FIELDS WHICH:

- ARE INHERENTLY NON-QUANTIFIABLE
- CONTAIN GENUINE UNCERTAINTIES
- CANNOT BE CAUSALLY MODELLED OR SIMULATED
- REQUIRE A JUDGMENTAL APPROACH

Source: Tom Ritchey, 2003-2009
ritchey@swemorph.com
What is MA used for?
- Complex issue which is not well formulated or defined; ("wicked problem")
- Well formulated/defined issue, but with no single solution (different solutions depending on…)
- Well defined problem with aspecific solution which can be worked out.

- Mess
- Problem
- Puzzle

(Russell Ackoff: Redesigning the Future, 1974; Michael Pidd: Tools for Thinking, 1996.)
HOW TO PERFORM MA

1. Need a 'messy' problem (just look around, no shortage)
2. Get 5-7 specialists to solve it in small iterative steps
3. Define parameters, 6-8 enough for most problems, real world can never be complete
4. Define values for each parameter (sometimes on a scale)
5. Get the morphological field everyone is happy with, keep it small not a table but a multidimensional configuration space
6. Get rid of all the values which are contradictory (resulting in internal inconsistencies)
7. How do you reduce the field? You do this by comparing each condition with every other condition, and asking the question: Can these two conditions coexist? This is done by way of a cross-consistency assessment, with the help of a cross-consistency matrix
### Proto morphological field

The totality of the parameters and their respective values is a morphological field. The table below illustrates the defined range of values for each parameter:

<table>
<thead>
<tr>
<th>Geographic priority</th>
<th>Functional priorities</th>
<th>Size and cramming</th>
<th>New construction</th>
<th>Maintenance</th>
<th>General philosophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropoles</td>
<td>All socio-tech. functions</td>
<td>Large, not crammed</td>
<td>With new construction</td>
<td>More frequent</td>
<td>All get same shelter quality</td>
</tr>
<tr>
<td>Cities + 50,000</td>
<td>Tech support systems</td>
<td>Large &amp; crammed</td>
<td>Compensation</td>
<td>Current levels</td>
<td>All take same risk</td>
</tr>
<tr>
<td>Suburbs and countryside</td>
<td>Humanitarian aims</td>
<td>Small, not crammed</td>
<td>New only for defence build up</td>
<td>No maintenance</td>
<td>Priority: Key personnel</td>
</tr>
<tr>
<td>No geo-priority</td>
<td>Residential</td>
<td>Small &amp; crammed</td>
<td></td>
<td>Priority: Needy</td>
<td></td>
</tr>
<tr>
<td>Victim</td>
<td>Type of crime (10 general examples)</td>
<td>Method</td>
<td>Types of solutions available</td>
<td>Legislation</td>
<td>Influence motives</td>
</tr>
<tr>
<td>-------------------------</td>
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<td>-----------------------------</td>
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</tr>
<tr>
<td>Consumer</td>
<td>Cheating on taxes/tolls etc.</td>
<td>False information to officials</td>
<td>Physical/visible controls</td>
<td>Standard regulations</td>
<td>Influence goal</td>
</tr>
<tr>
<td>External environment</td>
<td>Environmental crimes</td>
<td>Physical handling</td>
<td>Technical solutions</td>
<td>Order regulations</td>
<td>Influence means</td>
</tr>
<tr>
<td>Competitors</td>
<td>Fraud against companies</td>
<td>Bookkeeping</td>
<td>Administrative controls</td>
<td>Permission regulation</td>
<td>Reward</td>
</tr>
<tr>
<td>Employees</td>
<td>Crimes to reduce costs</td>
<td>Financial transactions</td>
<td>System and organisational solutions</td>
<td>Proceeding regulations</td>
<td>Sanction</td>
</tr>
<tr>
<td>Financiers</td>
<td>Limiting competition</td>
<td>International IT- transactions</td>
<td>NONE</td>
<td>NONE</td>
<td>NONE</td>
</tr>
<tr>
<td>Owners</td>
<td>Cheating with subsidies</td>
<td>Planned bankruptcy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The State</td>
<td>Swindles and stock influence</td>
<td>Illegal info transaction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market mechanisms</td>
<td>Insider crimes</td>
<td>Price fixing</td>
<td></td>
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<td></td>
<td>Company plundering</td>
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<tr>
<td></td>
<td>Money laundering</td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
CROSS CONSISTENCY MATRIX

<table>
<thead>
<tr>
<th>Functional priorities</th>
<th>Geo_prior</th>
<th>Functional</th>
<th>Size and construct</th>
<th>Maintenance</th>
<th>Philosophy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cities</td>
<td>Tech support</td>
<td>Large &amp;</td>
<td>More frequent</td>
<td>All get same</td>
</tr>
<tr>
<td></td>
<td>Suburbs</td>
<td>Humanitarian</td>
<td>Small &amp;</td>
<td>Current levels</td>
<td>All take same</td>
</tr>
<tr>
<td></td>
<td>Metropolitan</td>
<td>Residential</td>
<td></td>
<td>No maint.</td>
<td>Priority: Key</td>
</tr>
</tbody>
</table>

The matrix above illustrates the cross-consistency between different categories and sub-categories, showing the relationships and priorities among them.
OTHER METHODS OF FA FOR KN

• Social Network Analysis
• Cognitive Engineering
• Dynamic Ontology Modelling
Social Network Analysis (Krebs)

- [SNA] is the mapping and measuring of relationships and flows between people, groups, organizations, computers, URLs, and other connected information/knowledge entities. The nodes in the network are the people and groups while the links show relationships or flows between the nodes. SNA provides both a visual and a mathematical analysis of human relationships. Management consultants use this methodology with their business clients and call it Organizational Network Analysis [ONA].

- To understand networks and their participants, we evaluate the location of actors in the network. Measuring the network location is finding the centrality of a node. These measures give us insight into the various roles and groupings in a network -- who are the connectors, mavens, leaders, bridges, isolates, where are the clusters and who is in them, who is in the core of the network, and who is on the periphery.

- Centrality measures: Degree Centrality, Betweenness Centrality, and Closeness Centrality.
Cognitive Engineering comprises a variety of methods to describe, model, and simulate. This includes:

- Cognitive Task Analysis
- Knowledge Elicitation
- System Evaluation Methods
- Theoretical Frameworks
- Cognitive Processes
- Behavioral Processes
- Task Analysis
- Computational Task Simulation
- Computational Cognitive Modeling
- Erroneous Actions
- Human Reliability Analysis
- Human-Machine Systems
- System-Oriented Methods
- Cognitively-Oriented Methods

For more information, visit: http://mentalmodels.mitre.org/cog_eng/
<table>
<thead>
<tr>
<th>Cognitive Task Analysis</th>
<th>Method</th>
<th>Concept Definition</th>
<th>Requirements Analysis</th>
<th>Function Analysis</th>
<th>Function Allocation</th>
<th>Task Design</th>
<th>Interface and Team Development</th>
<th>Performance, Workload, and Training Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA.1</td>
<td>Applied Cognitive Task Analysis (ACTA)</td>
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<td>IA.2</td>
<td>Critical Decision Method (CDM)</td>
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<td>IA.3</td>
<td>PARI Method</td>
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<tr>
<td>IA.4</td>
<td>Skill Based CTA Framework</td>
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<tr>
<td>IA.5</td>
<td>Decompose, Network, and Asses (DNA) Method</td>
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<td>IA.6</td>
<td>Task-Knowledge Structures (TKS)</td>
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<td>IA.7</td>
<td>Goal-Directed Task Analysis (GDTA)</td>
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<tr>
<td>IA.8</td>
<td>Cognitive Function Model (CFM)</td>
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<td>IA.9</td>
<td>Cognitively Oriented Task Analysis (COTA)</td>
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<tr>
<td>IA.10</td>
<td>Hierarchical Task Analysis (HTA)</td>
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<tr>
<td>IA.11</td>
<td>Interacting Cognitive Subsystems (ICS)</td>
<td></td>
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<tr>
<td>IA.12</td>
<td>Knowledge Analysis and Documentation System (KADS)</td>
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<tr>
<td>IA.13</td>
<td>Team CTA Techniques</td>
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</tr>
</tbody>
</table>
DYNAMIC DOMAIN/ONTOLOGY ENGINEERING

We are familiar with 'classic' ontology development, in the future we ll rely increasingly on 'dynamic' (evolutionary) ontology modelling techniques
CONCLUSION

I illustrate some aspects of the problem space and provide rationale and brief overview of FA for STS

----- OOO ------

The motivating questions for this presentation is
*What formal methods are adequate for the modelling and analysis of knowledge driven socio technical networks?*

we can conclude that

logic based, polymorphic
FA methods are needed

It is expected that new methods will result from the layered combination of existing methods benefit from agile approach
Seven Principles of Sociotechnical Systems Engineering ...
Development methods must support formal analysis for dependability. SociotechnicalSystems ...
www.indeedproject.ac.uk/wstse/programme/.../thomas08principles.ppt
http://www2.chi.unsw.edu.au/pubs/COIERA-07-STS.pdf
http://findarticles.com/p/articles/mi_m4153/is_n2_v51/ai_15382647/
“Never underestimate the power of a few committed individuals to change the world. Indeed, it’s the only thing that ever has.”

Margaret Mead
SGSR President 1972-1973

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