Computational Cognitive Modelling

COGS 511-Lecture 2

Unified Theories of Cognition, Cognitive Architectures vs Frameworks: COGENT

Related Readings

- Readings: Langley et al. (2009) Cognitive Architectures
- Optional:
  - Newell's Precis of Unified Theories of Cognition, in Polk and Seifert (2002)
  - Abrahamsen and Bechtel (2006) Phenomena and Mechanisms
  - Taatgen, N. A. (1999). *Learning without limits: from problem solving toward a unified theory of learning*. Doctoral Dissertation, University of Groningen, The Netherlands. (Ch. 2)
  - Taatgen, N. A. & Anderson, J. R. (2009). The Past, Present, and Future of Cognitive Architectures. *topiCS in Cognitive Science*, 1-12. Available Online from http://act-r.psy.cmu.edu/people/index.php?id=92
  - See also Chapters 3,4, and 5 of Polk and Seifert (2002)

Some slides are adopted from COGENT tutorials - http://cogent.psyc.bbk.ac.uk/.

Symbols

- Any entity that bears content within a system
- Anything that represents; a token that stands for something else in the specified context
- Has content, organization, format
- Can be external or internal (mental)
- Accessed and retrieved by processes

Symbol Systems

- Consist of
  - A memory, containing independently modifiable structures that contain symbols
  - Symbols, patterns in the structures providing distal access to other structures
  - Operations, taking symbol structures as input and producing symbol structures as output
  - Interpretation processes, taking structures as input and executing operations
- Requirements: Sufficient memory and symbols, complete composability of structures by the operators, and complete interpretability

Physical Symbol Systems Hypothesis

- (Newell and Simon, 76) “The necessary and sufficient condition for a physical system to exhibit general intelligent action is that it be a physical symbol system. A system is intelligent to the degree it bears all its knowledge in the service of its goals”.

Commitments of the Physical Symbol System Hypothesis

- Use of symbols or systems of symbols
- Causal Decomposable Models of Explanation
- Empirical
- Must be realized in the brain, thus can be implemented in a massively parallel way

Symbolic Representations

Symbolic Proposition: a statement that consists of symbols which refer to objects, properties and relations

Symbolic Rule: for manipulation and transformation of symbol structures

- First Order Logic
- Other Logics
- Semantic Nets, Conceptual Graphs
- Frames, Scripts
- Production Rules
- Symbolic Learning Mechanisms: eg case-based reasoning, inductive reasoning

Symbolic Modelling

- Properties of symbolic systems must be satisfied: systematicity, compositionality
- General Purpose Symbolic Programing Languages, Cognitive Architectures/Frameworks, Production Systems

Production Systems

- Rules: IF-THEN Rules
- Rule Database (long term memory) vs Working Memory (WM) vs Goal Memory
- Recognize-Act Cycle:
  - Match the variables of the antecedents of a rule with data recorded on WM
  - If more than one rule fires, apply a conflict resolution strategy
  - Add new items to WM, delete or update the old items – do necessary actions
- Conflict Resolution: Strategies based on recency, utility, or specificity etc. possible
- Forward-backward or bi-directional reasoning: ways of traveling through state space

Attacks to Symbolic Approaches

- Frame Problem
- Symbol Grounding Problem
- Serial vs Parallel: Neurological Plausibility
- Non flexibility in explaining acquisition, learning, deficits, evolution
- Computation without representations and explicit algorithms is possible

Other Approaches

- Connectionism
- Dynamicism
  - Will be evaluated in more depth in coming weeks...

Phenomena vs Mechanisms

- Exs: Symbolic approaches to describing certain cognitive phenomena vs connectionist mechanisms to specifying mechanisms to explain them.
  - Exs: Optimality Theory and Connectionism, Language Acquisition and Statistical Learning

Another Dichotomy...

- Microtheories vs Unified Theories of Cognition....
- What is unified?
  - Cognitive architectures vs frameworks (such as connectionism)

Problems About Microtheories of Cognition

- Each individual discipline contributes microtheories, each stated in a different way.
- How do they fit into whole picture?
- Comparative evaluation may not be possible.

Unified Theories of Cognition

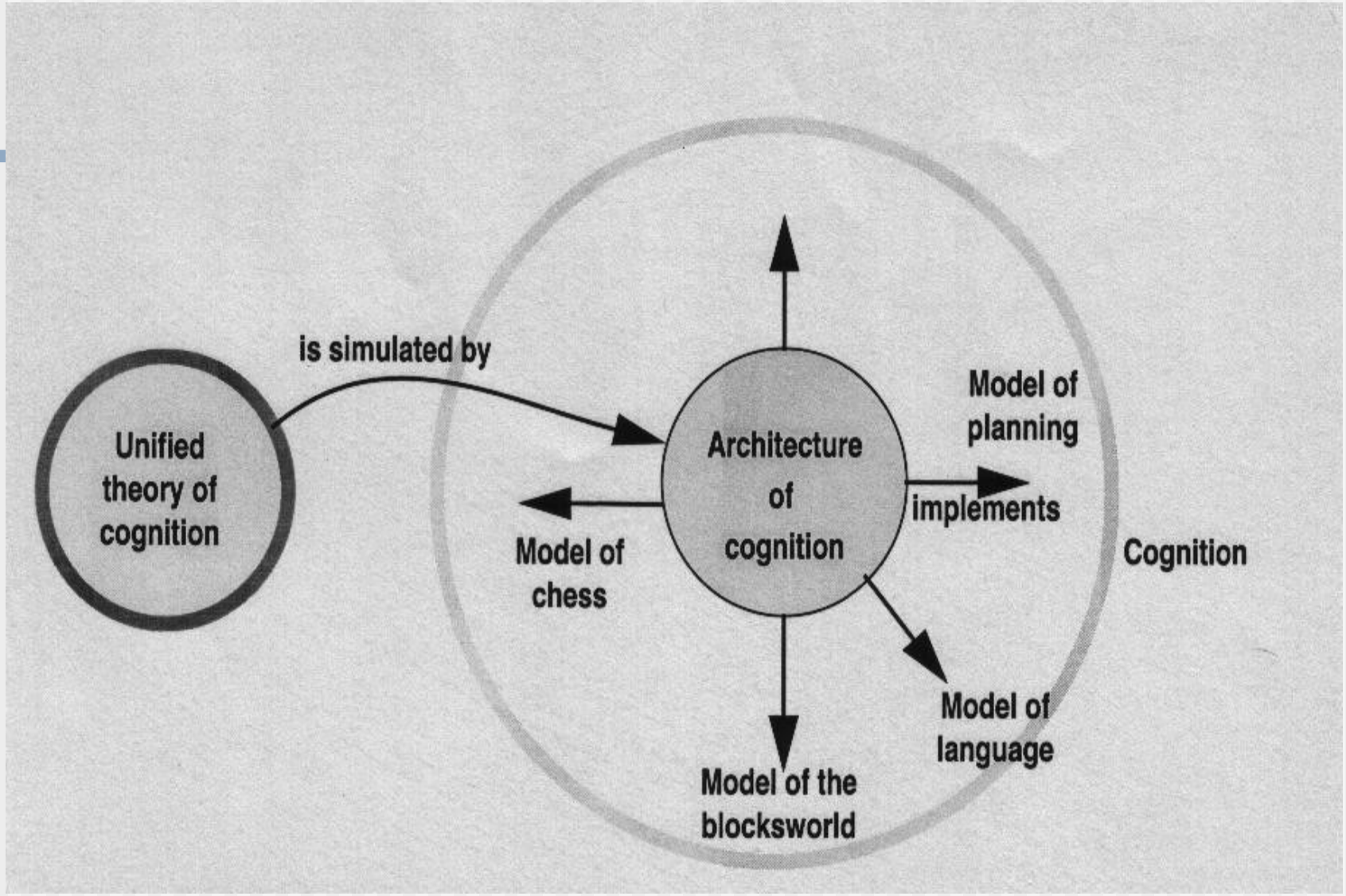
- Single sets of mechanisms that cover all of cognition.
- Multiple candidate theories should cumulate, be refined, reformulated, corrected and expanded.

Recommendations for Unified Theories of Cognition

- Have many unified theories of cognition
- Develop consortia and communities
- Be synthetic – incorporate not replace local theories
- Modify, even radically change
- Create data bases of results and adopt a benchmark philosophy
- Make models easy to use and reason about
- Acquire one or more application domains for support (Newell, 2002)

Cognitive Architectures

- “Unified theories of cognition will be realized as architectures, (nearly) fixed structures that realize a symbol system.” (Newell, 1990)
- Relatively complete proposals about the structure of human cognition
- An architecture provides and manages the primitive resources of an agent.
- ARCHITECTURE*CONTENT = BEHAVIOUR
- One-to-many mappings between symbol systems-architectures-technologies



(Taatgen, 1999)

Cognitive vs. Computer Architectures

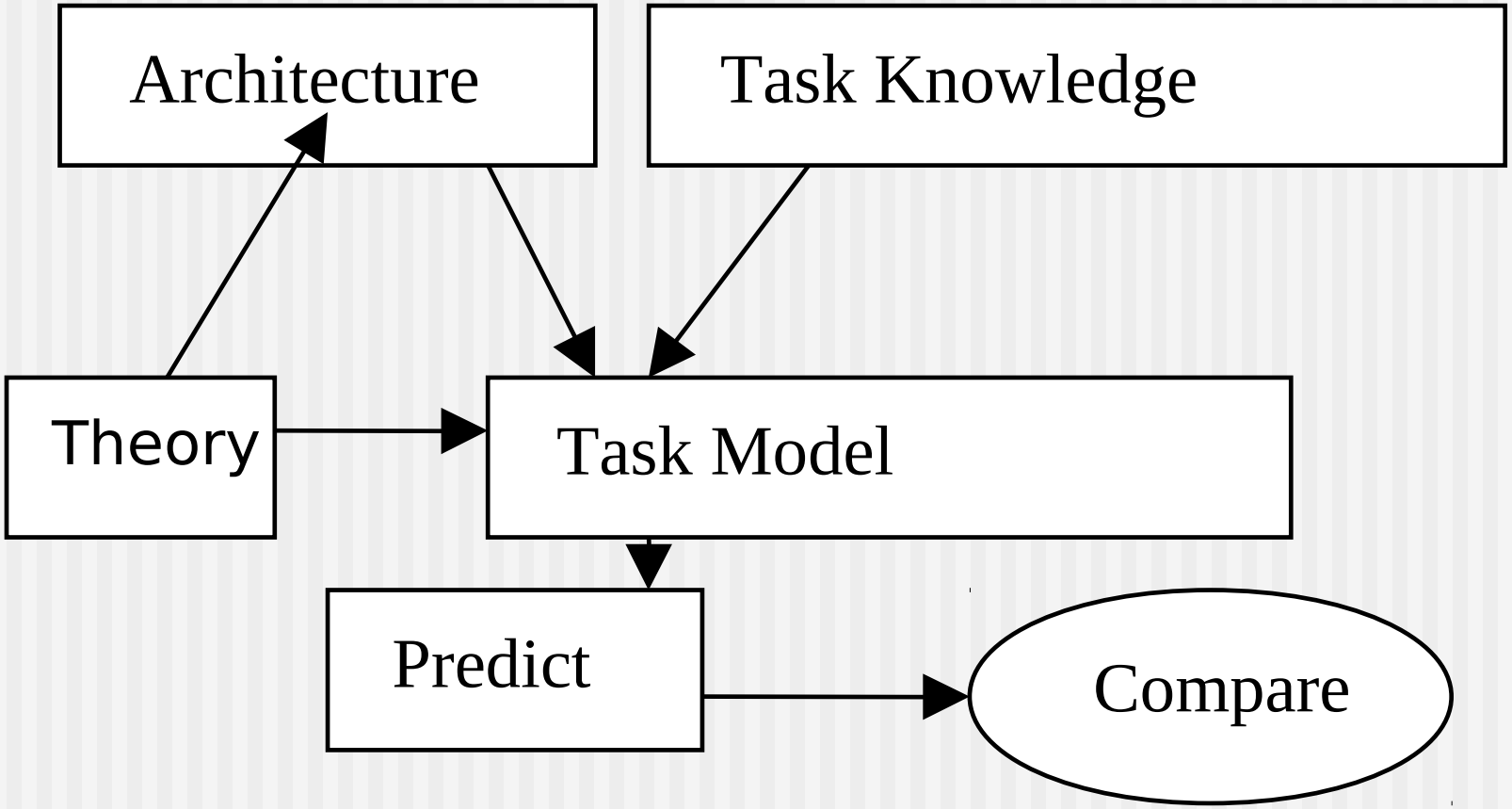
- Runs a model
- Is itself a model of a theory
- Makes predictions, needs to be evaluated against experimental data

- Runs a program
- Part of the design of the computer
- Is actually working, evaluation by benchmarking, etc.

Architecture vs Task Model

- Fixed structures common, constant and available to all tasks
- Task model: a system (required knowledge, mechanisms etc) implemented on the architecture to generate specific predictions with respect to a certain task
- An architecture should demonstrate flexibility and generality rather than success on a single domain

Cognitive Architectures in Perspective



Adopted from (Taatgen, 1999)

Common Elements of Cognitive Architectures

- Production Systems with Conflict Resolution
- Connectionist/Associationist aspects: modelling forgetting, utility etc.
- Declarative vs Procedural Memory
- Goals, Long Term vs Short Term Memory
- Learning
- Sensory buffers and interaction with sensory (vision, motor etc) input/output
- Experiment set-ups and evaluation

The Real Time Constraint on Cognition

- Biological Band (100 µsec – 10msec)
- Cognitive Band (100msec – 10sec)
- Rational Band (Minutes to hours)
- Social Band

Human cognitive architecture must be shaped to satisfy the real time constraint.

Cognitive Architectures vs. Frameworks/Tools

- **SOAR**
- **ACT-R**
- 4CAPS
- EPIC
- PSI
- Clarion
- Icarus
- Prodigy

- **COGENT**
- CogNet/iGEN
- CogAff
- ConAg
- Connectionist Toolkits –e.g. Emergent (aka PDP++)
- Computational Neuroscience Toolkits (Genesis, NEURON)

Advantages of Cognitive Architectures

- Learnability and Support
- Inventory of Models and Data
- User Interfaces
- Portability
- Public Design Specifications
- Modularity, Modifiability

Problems with Cognitive Architectures

- Description as cognitive theory vs description as a computational model vs the software itself
- Independent testability of individual assumptions
- Aspects of the architecture that are implementational details: special I/O functions, effective Working Memory management
- Small changes- Big effects

3CAPS/4CAPS

- Just and Carpenter, see link on METU Online
- Capacity Constrained Activation Theory
- Each representation has an activation level the reflects its accesibility; only when activation level is above a threshold, it is in working memory and can enable a production to fire. Multiple productions can fire in a given cycle.
- Limits in resource consumption: if the total demand for activation exceeds the allowable maximum, slowing down of processes or forgetting may occur.
- A hybrid system like ACT-R
- Modelling of differences in reading, spatial problem solving, agrammatic aphasia
- No learning (?)

EPIC

- Executive Process/Interactive Control- Meyer and Kieras
- Study of bottlenecks in human multiple task performance (evidence against Response Selection Bottleneck)
- Perceptual and motor processors interacting with a cognitive processor (all working in parallel) that has a working memory, long term memory and a production rule interpreter
- Parallel rule testing and firing
- No learning (?)
- Now, Integrated into ACT-R (previously ACT-R/PM)

PSI

- Dörner et al.
- (Some) Documentation in German
- Building psychosocial agents – motivation, emotion and acquisition of ontologies via interaction based on semantic nets
- MicroPsi – more agent-oriented development

http://www.cognitive-agents.org/

COGNET

- Zachary et al., CHI Systems, see www.chisystems.com
- A theory neutral framework for modelling cognitive agents at near-expert/expert level of performance on realtime/multi tasks
- Single long term/working memory; parallel perceptual, motor and cognitive systems
- Integrated Development Environment –iGEN toolkit (not free)

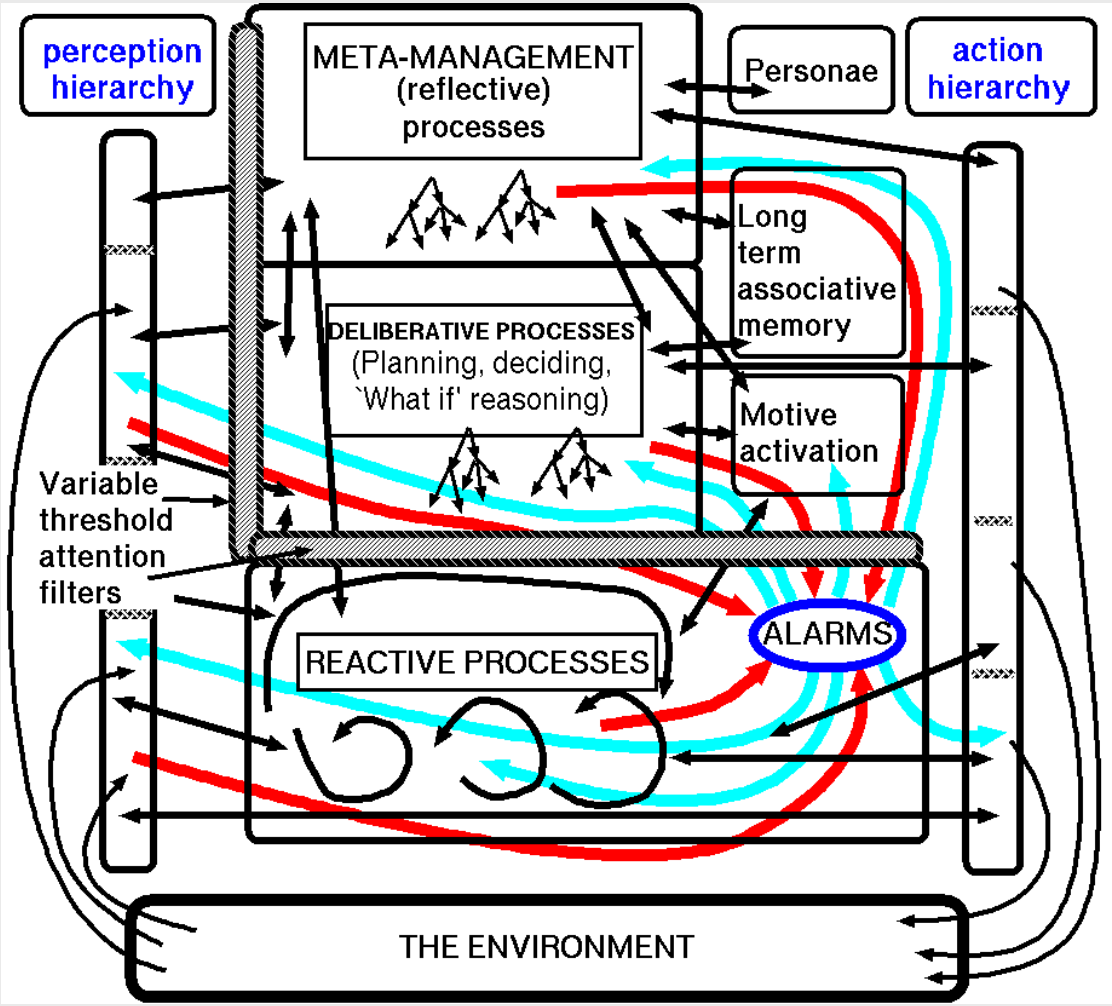
CogAff – Cognition and Affect Project

- http://www.cs.bham.ac.uk/~axs/cogaff.html

(Sloman et al.)

- SimAgent Toolkit – for developing cognitive agents (free)
- Cosy project- on cognitive robotics, now followed by CogX project
- Multilevel, concurrent components within perceptual, central and motor sub-systems
- Layered approach in dealing with emotions: reactive, deliberative, reflective layers

H-CogAff Architecture



From http://www.cs.bham.ac.uk/~axs/cogaff.html

ConAg

- Franklin et al.
  http://ccrg.cs.memphis.edu/projects.html
- Frameworks for “conscious” agents: inspired by Baars’ Global Workspace Theory
- A “framework” in Java in codelets – metacognition,memory, perception, attention management
- IDA model: Apparently a successor to ConAg; personnel assignment task for Navy – followed by various LIDA – Learning IDA models

Cognitive Architectures vs. Frameworks/Tools

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COGENT: A sample modelling tool

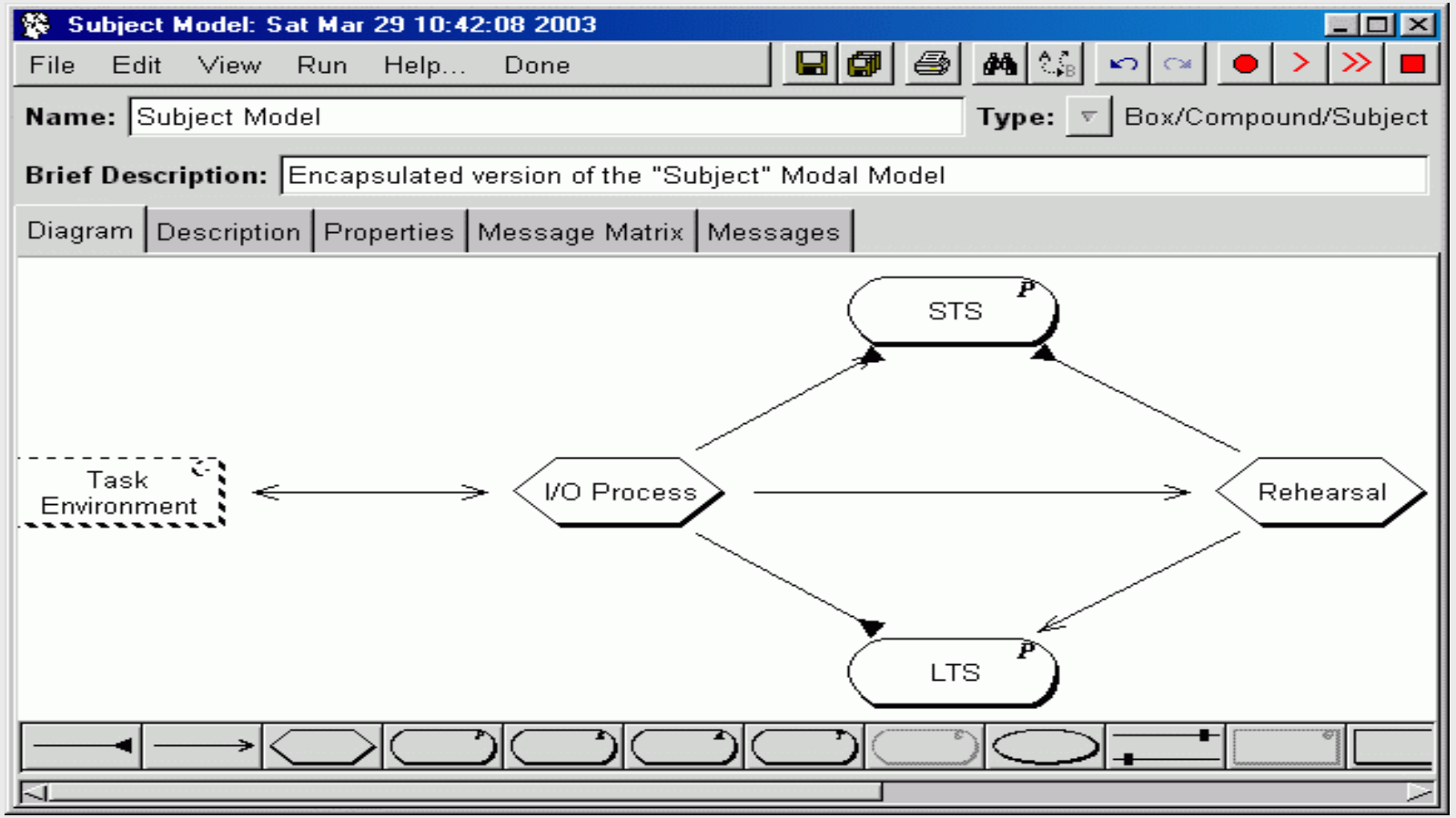
- COGENT is a modelling environment. It is not an architecture
- COGENT provides facilities to support the development and evaluation of symbolic and hybrid models
- COGENT is not appropriate for the development of purely connectionist models
- COGENT is domain general. It has been used to develop models of: Reasoning, Problem Solving, Categorisation, Memory, Decision Making, ...

COGENT: Principal Features

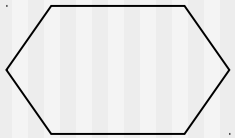
- A visual programming environment;
- Research programme management tools;
- A range of standard functional components;
- An expressive rule-based modelling language and implementation system;
- Automated data visualisation tools; and
- A model testing environment.

Visual Programming in COGENT

- Allows users to develop cognitive models using a box and arrow notation that builds upon the concepts of functional modularity and object-oriented design.



Visual Representation



processes that transform information

buffers that store information

compound systems with internal structure

sending message to a process

reading information from a buffer

Standard Functional Components

- A library of components is supplied:
  - Rule-based processes
  - Memory buffers
  - Simple connectionist networks
  - Data input/output devices
  - Inter-module communication links
- Components can be configured for different applications

Rule-Based Modelling Language:

Processes may contain rules such as:

IF operator(Move, possible) is in *Possible Operators*
evaluate_operator(Move, Value)

THEN delete operator(Move, possible) from *Possible Operators*
add operator(Move, value(Value)) to *Possible Operators*

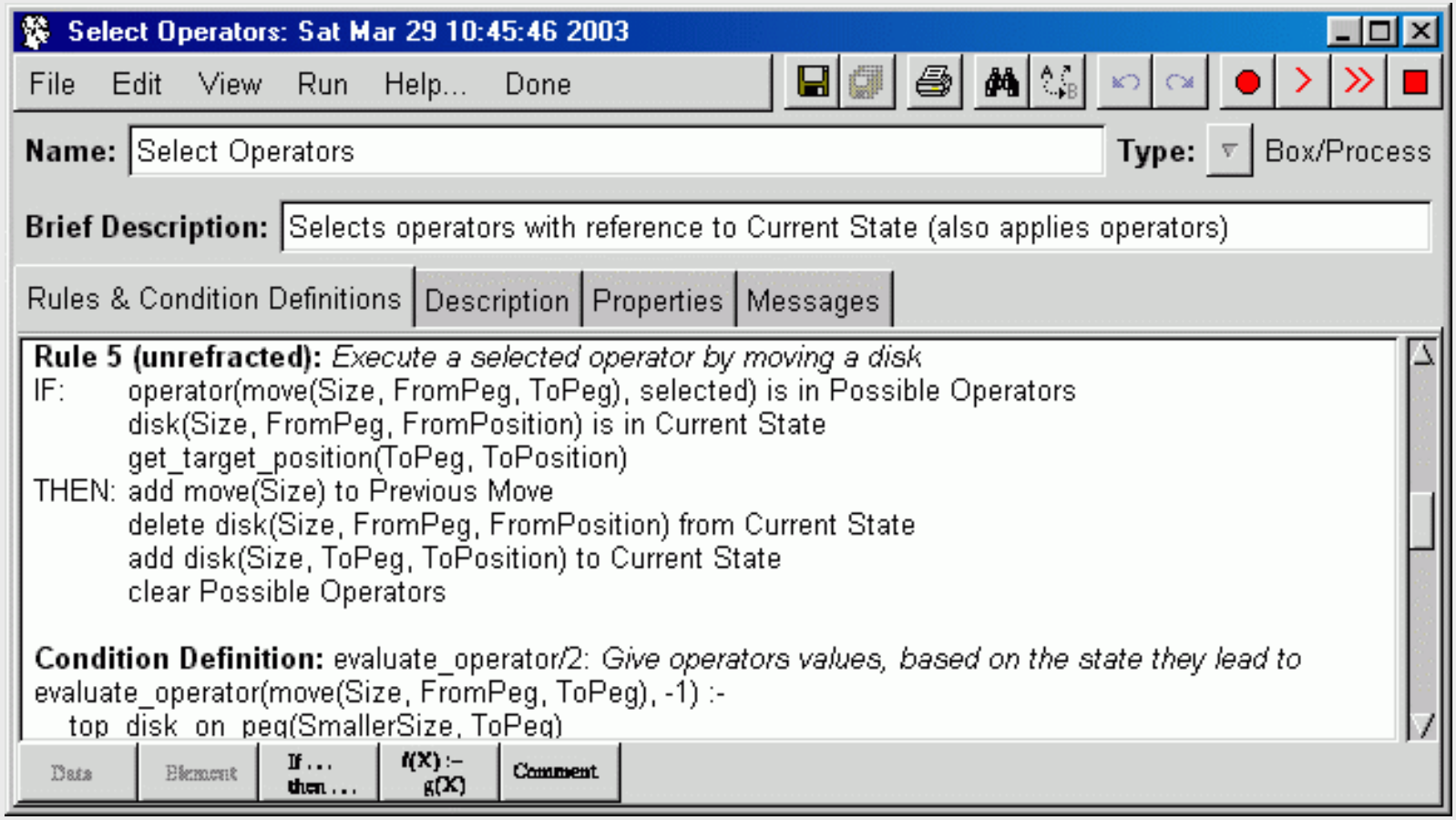
Rule-Based Modelling Language:

COGENT's representation language is based on Prolog:

IF operator(Move, possible) is in *Possible Operators*
evaluate_operator(Move, Value)
THEN delete operator(Move, possible) from *Possible Operators*
add operator(Move, value(Value)) to *Possible Operators*

Terms beginning with an upper-case letter are variables

Rule-Based Modelling Language:



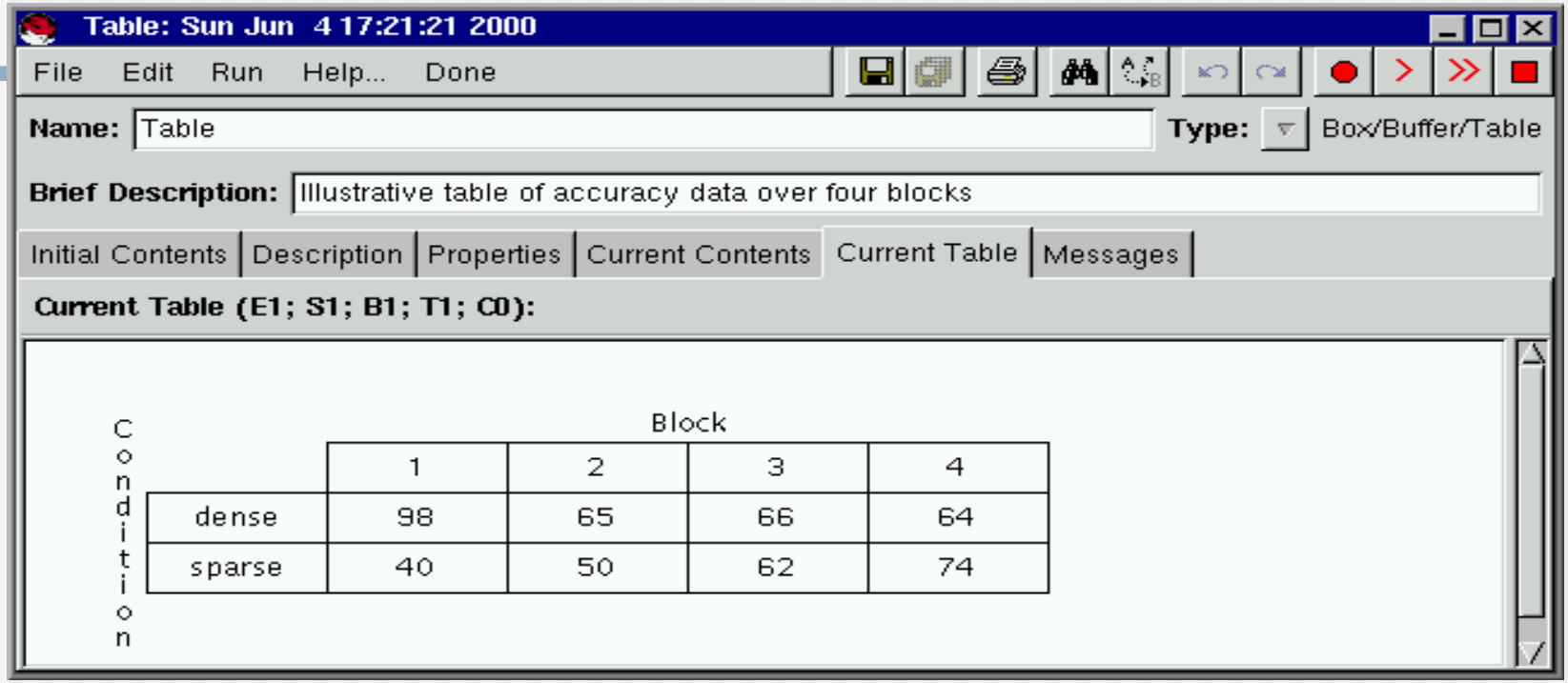
How do rules get activated?

- Autonomous rules test their conditions on every processing cycle and fire when their conditions are met. Triggered rules only test their conditions when they are triggered by the arrival of an appropriate message.

Firing Rate of the Rules

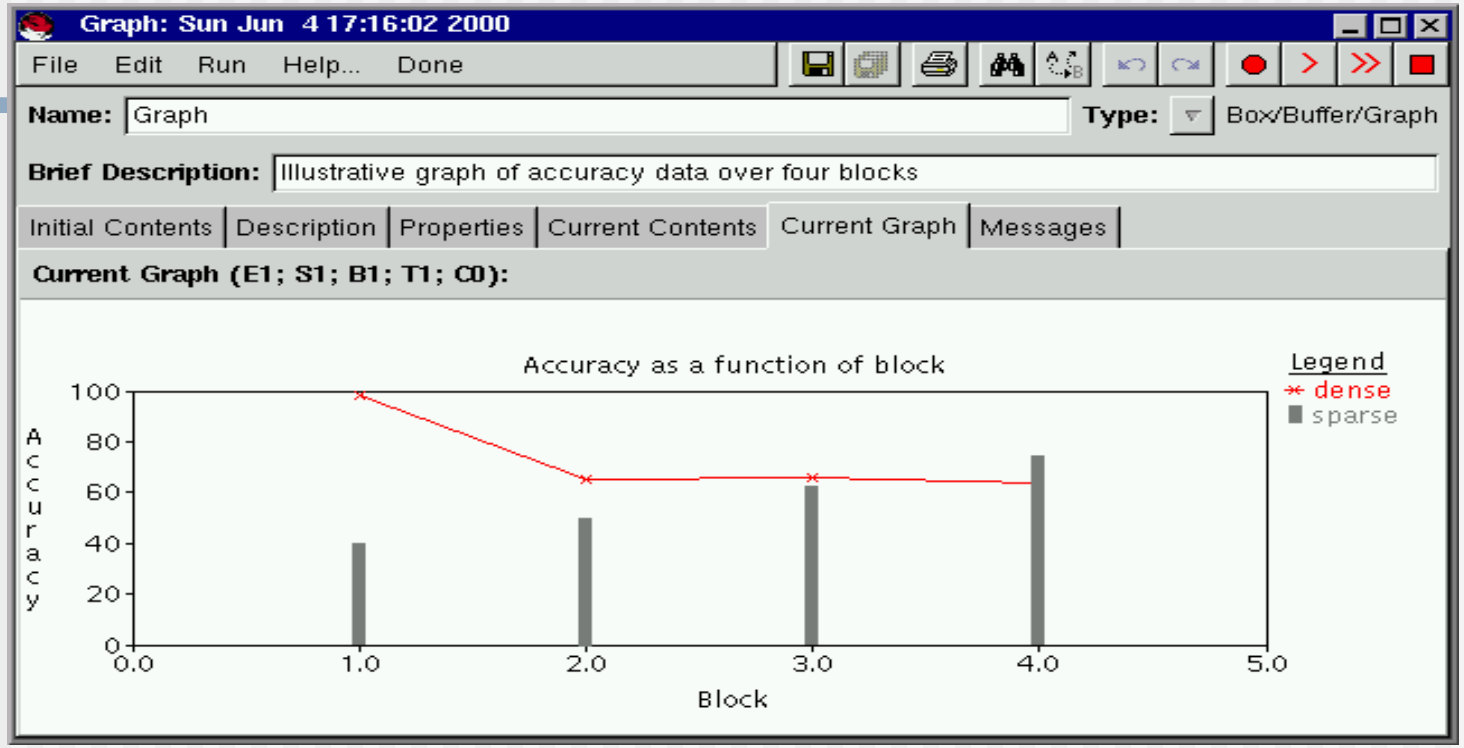
- Some rules should fire just once for each possible instantiation of its variables, and the rule should not fire on every cycle with the same variable binding. This is enabled with the refraction parameter.

Data Visualisation Tools: Tables



- Updated dynamically during the execution of a model
- 2 types of tables:
  - Output Tables → write-only
  - Buffer Tables →read / write

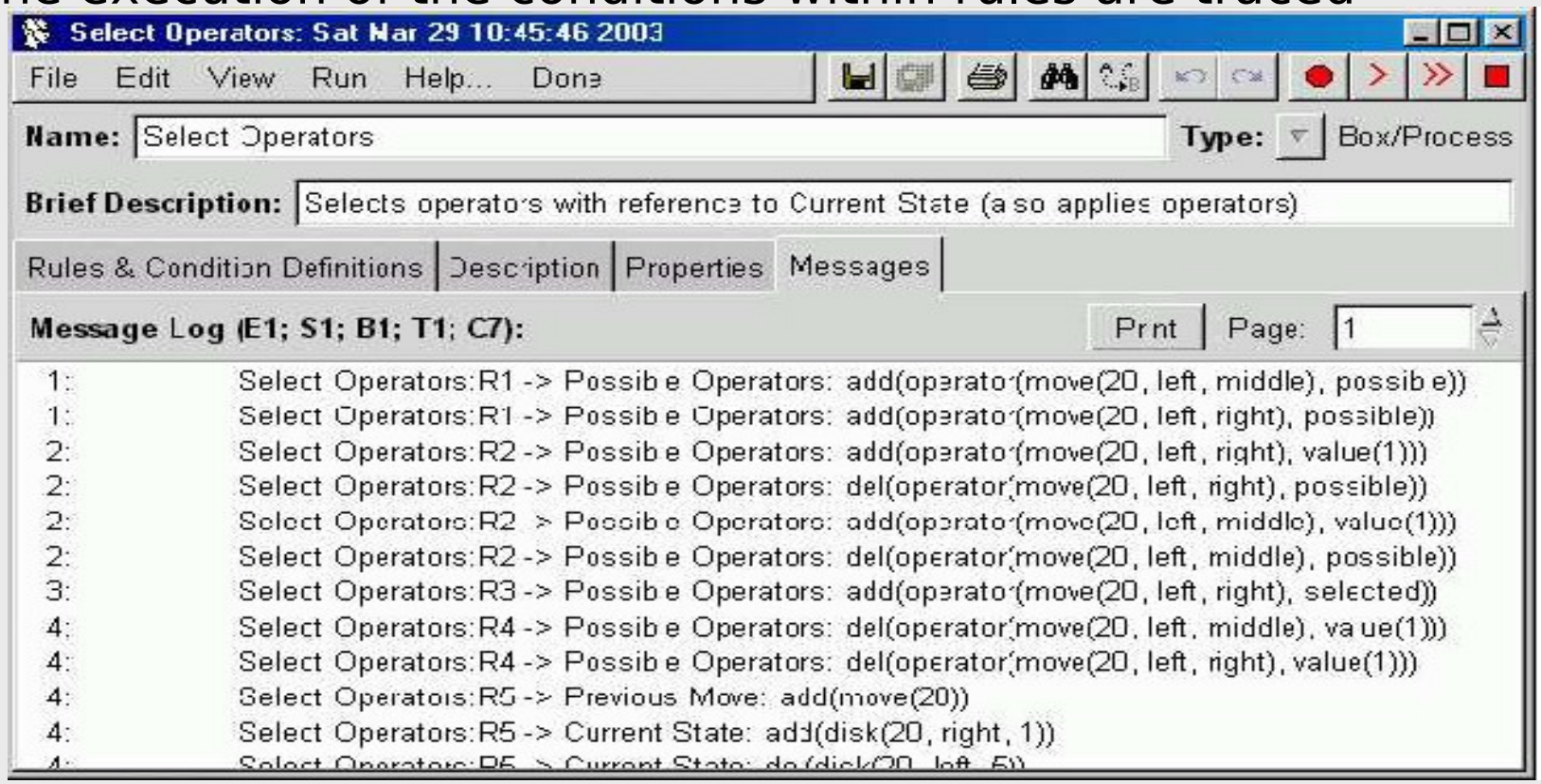
Data Visualisation Tools: Graphs



- Updated dynamically
- Several formats (line graphs, scatter plots, bar charts)

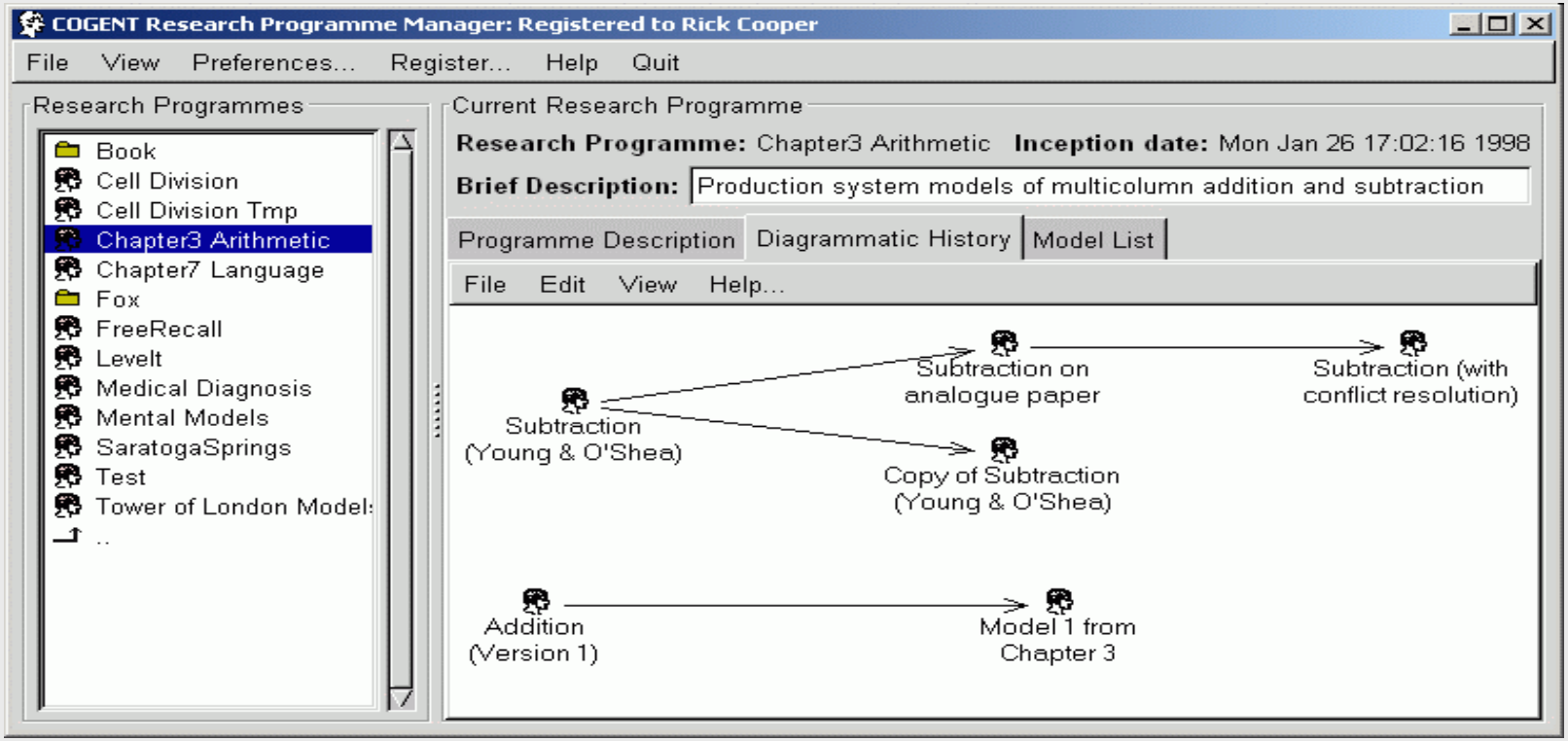
The Model Testing Environment

- Monitoring is provided through the Messages view available on each component's window. This view shows all messages generated or received by a component.
- the execution of the conditions within rules are traced



Research Programme Management

- Managing sets of models
- Each node in the tree corresponds to a separate model
- Links in the tree show ancestral relations between successive versions of the same model
- several versions of a model may be explored in parallel

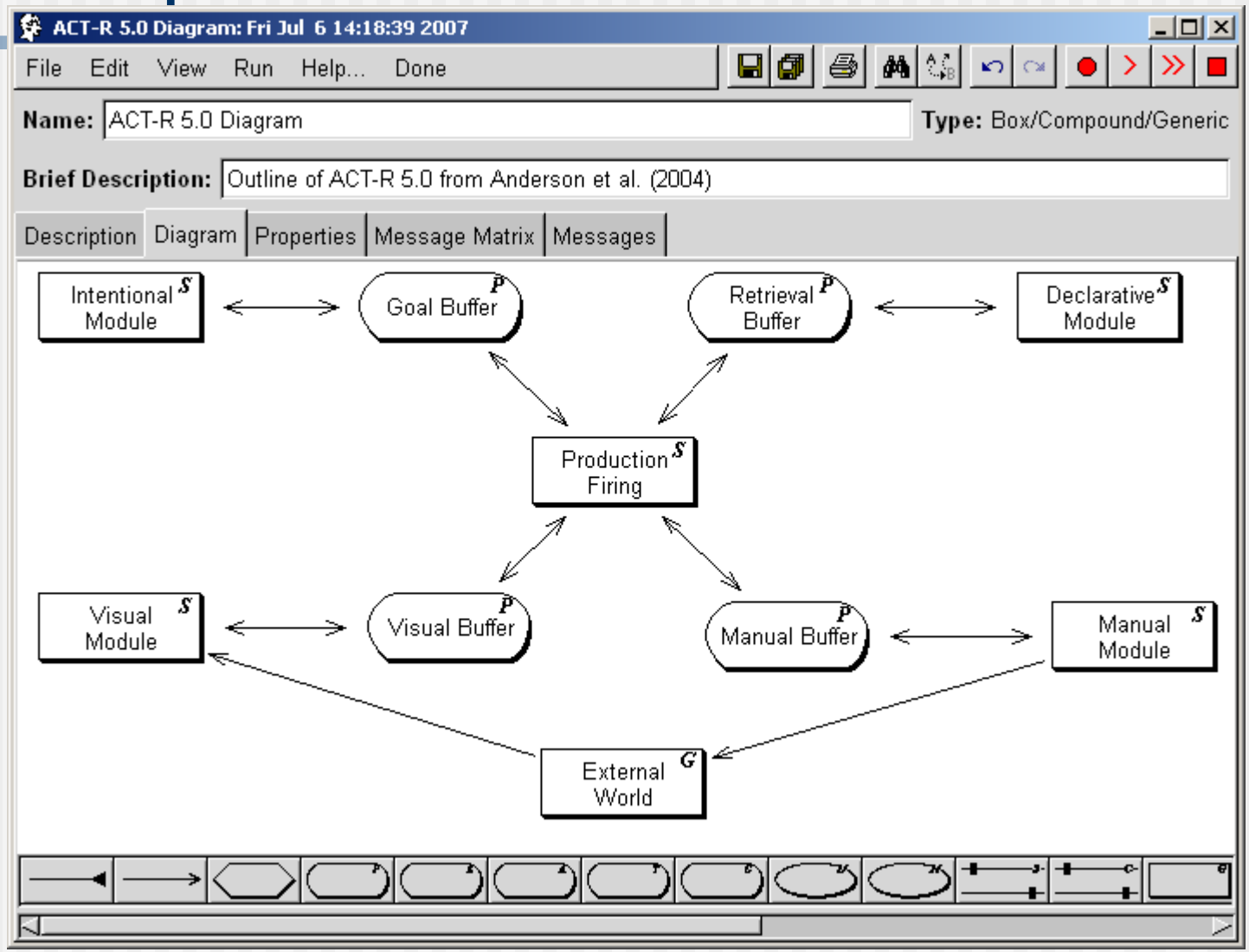


Some COGENT Models

Domains in which COGENT has been applied (see COGENT book in library):

- Memory (Free recall)
- Arithmetic (Multicolumn addition and subtraction)
- Mental Imagery (Shepard's mental rotation task)
- Problem Solving (Missionaries, Towers of Hanoi, Cryptarithmetic)
- Deductive Reasoning (Syllogisms, Inferences)
- Categorisation/Decision Making (Medical diagnosis)

ACT-R 5.0: Component Processes



COGENT Version 3: Planned Features

1. Fresh look and feel
2. Additional drawing tools
3. Improved navigation facilities
4. Revised box / object hierarchy
5. Improved efficiency on Windows platforms

Public release of V3.0 expected in first quarter of 2009 – but has not been announced yet!

From http://cogent.psyc.bbk.ac.uk

Lecture 3

- ACT-R
  - Readings: Anderson et al. An Integrated Theory of Mind
- SOAR
  - Lehman et al.'s (2006) A Gentle Introduction to SOAR
- Due: Report in writing (by email) to course assistant
  - your project groups and
  - your selected topics of individual review – times will be determined after selection of topics...
- Next Week: ACT-R Practical Session