p1-2
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Empirical Modelling for Educational Technology

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Content

1. Background

1.1. A perspective on IT in education

Nature of knowledge, intelligence, learning?
Central to education and to Empirical Modelling (EM)

Motivation for EM research
- fundamental issues in programming and IT
  [especially alternatives to a logicist view]
- problematic issues arising from the use of IT in education
  [especially associated with "collaborative" use of computers]

Thesis: understanding the role and potential role of IT in education
involves examining perspectives on knowledge in different disciplines
and the extent to which these are supported by approaches to IT

Leads to a perspective that is not specifically associated with IT
Role of (computer-based) artefacts and instruments in education

Interpretations of knowledge in disciplines
type: facts, skills, theories, conventions, phenomena and artefacts
character: subjective, objective, subject to controversy
status: evolving, partial, incremental, provisional

[The challenge of "Ignorance Representation"]

Knowledge as represented in computer use
procedurally: as process, algorithm
declaratively: via logic and rules, codified information
experientially:
as medium for recording aspects of state as they are experienced
as interface for presenting and manipulating models of state

Problems surrounding IT in education reflect conflict between two views of knowledge

Problems surrounding IT in education

View from the target discipline

IT introduction should ideally enfranchise all aspects of the discipline
IT is frequently associated with a closed-world view
IT => stereotyped pedagogy, inflexible interaction, staleness in repeated use
socially and situationally problematic: e.g. modelling the student, classroom use

Possible paradigms for introducing IT

computer as tutor, computer as tool, computer as simulation
hard to integrate these various standard roles: e.g. presentation and discovery
need to enable "collaborative learning with computers" [Crook]

View from IT

end-user programming is problematic
changing requirements is known to be hard
full automation easier than teacher/pupil collaboration
new programming paradigms regarded as inappropriate/irrelevant
realistic aspirations vs hype in AI programming
hard to assess significance of technological advance (e.g. multi-media, WWW)

Two apparently independent concerns being raised:

how to make IT for education more effective in teaching / learning?
how to make development of IT for education more efficient / accessible?

If IT is to fulfil its promise in education, must address:

(a) closer integration of IT with other disciplines, taking account of social and situational factors
(b) progress towards better methods of enabling non-specialists to adapt / develop software and environments, tackling basic issues in end-user programming / reqts

Thesis: problems (a) and (b) are related

principles of knowledge representation that bring closer integration of disciplines with IT
ALSO
assist software development and make significant impact on fundamental problems of CS

Knowledge representation in Empirical Modelling

Empirical Modelling is concerned with the activities
associated with the transition from subjective to objective knowledge

logicism / formal representation / formal language <-> objective knowledge

representation of subjective via artefact: juxtaposition / blending of experiences

artefact can be - but is not necessarily - computer-based
[slogan: computer liberates the design and construction of artefacts]

juxtaposition of experience of the artefact with independent "external" experience
external may mean what is deemed to be "real-life" (cf status of objectivity)

2. Introduction to Empirical Modelling

Motivation

Issues for IT in education

Making the development of educational software accessible to teachers ....

Enhancing the quality of educational software for learners ....

Propose Empirical Modelling as a way to meet both these demands

principles of model construction are linked to the learning process => good educationally

conception of model linked to its construction => effective accessible software development

Principles of Empirical Modelling

Elaborate a model of a phenomenon with reference to a projected causal account ....

[phenomena used very broadly to encompass even surreal experiences or works of art]

Involves systematic identification of
observables
dependencies: patterns of correlated change to observables
agents: instigators of state-change

Also identify observables that are presumed to account for stimulus-response patterns in agent interaction and classify these with respect to each agent

Leads to the construction of behavioural models, in general partially under super-agent control

A single model incorporates an uncircumscribed family of open and closed behaviours

These include

experimental environments
incomplete models from early stages of the development
intrinsic behaviours associated with automatic agents

Observation, dependency and agency

• observables, dependencies and agents from an egocentric "1st person" perspective

observable = feature of my experience that I can directly apprehend, to which an identity can be attributed
an observable typically manifests itself through many different forms / states / values

dependency = a pattern through which I perceive observables as correlated in change

[an indivisible relationship cf relations amongst cells in a spreadsheet]

action: my own actions are those changes to observables that I am conditionally able to effect

The effect of my action encompasses all the contingent changes to observables arbitrated by dependencies
In thsi way it is then context-dependent cf moving a lever.

agent: my own agency is determined by what actions I can conditionally perform

The identification of personal observables, dependencies, actions and agency is an empirical matter:
associated with observation and experiment.

Such concepts can be ephemeral to an arbitrary degree: consider
the identity of a cloud
the shadow cast by the lights of a passing car
the moment at which I can act to intercept a ball

What I deem to be observable can be influenced by skill, external convention and familiarity

For instance:
identifying personal tutees
knowing when the cricket match has been won
learning how to unlock a door

Notice that the criteria for an observable ("having an identity" and "being directly apprehendable") are broad enough to encompass more than "discrete sensory particulars"
[cf Radical Empiricism - William James, 1910]

e.g. a trained musician may know instantly that a particular configuration of notes is a dominant seventh.

Other examples:
corner of a table
voltage or current (made explicit by instrument, or commonsense knowledge)
the winning of a cricket match (established by convention)

What is associated with a 1st person perspective is all I can speak for
1st person knowledge and experience is distinctively different from any other [cf William James]

Contexts for personal observation

Refer to a situation in which observables, dependency and agency are perceived as a **context**

many contexts typically interleave and overlap in the stream of consciousness

"I write this text" interleaves with "I go for a walk", "I feed the cat", etc
and overlaps with "I see black and white patterns on the screen", "I recall a visit to Ottawa" etc

The identification of contexts is itself an imprecise and empirical process

concentration is associated with focus upon a particular context
"I write this text and try to forget that tomorrow is Monday"
contexts have intrinsic integrity and continuity, but can be suspended and resumed
"I return to writing this text"

Experiences drawn from one context can be appropriated to another

- cf use of artefacts: piece of string to record a length, finite state machine, map

- development of instruments
  cf associating response of artefact with state change, as in sundial

- development of skills
  cf associating physical movement with effect, as in playing middle C

- activities such as "blending" involve creative invocation of overlapping contexts
  cf the use of cartoons

Contexts are to some extent associated with roles I can play, and be deemed to be playing simultaneously

An illustrative example: different roles in which to observe a traffic light

There are many roles in which I can interact with a particular traffic light, and associated observables:

Traffic light designer (aesthetic)

shape, location, colour, size of lights

Driver at road junction

colour pattern, phase of lights, traffic convention

Traffic light installer

time delays within cycle, traffic sensors, visibility in context

Traffic light maintenance

electrical components, voltages, currents, resistances

Mere observer: casual observer, dog owner, poet, short-sighted person, hallucinating person

effects of sunset, shadow, poetic / imaginative interpretations
traffic light as lollipop, as tower of faces, as indistinct blobs of colour

Objective observer: a traffic police monitor

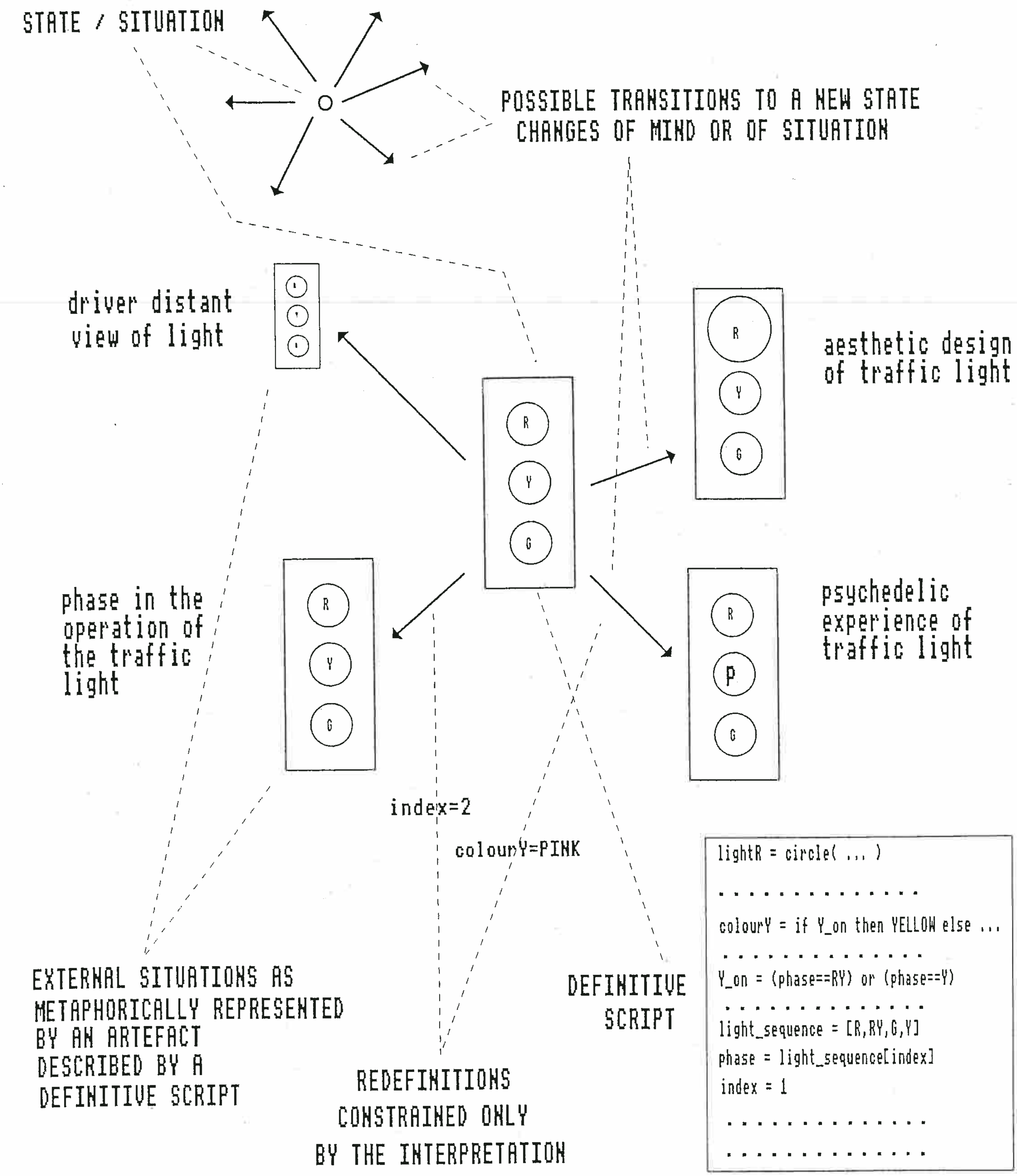
speeds and locations of cars, synchronisation of car motion and light status

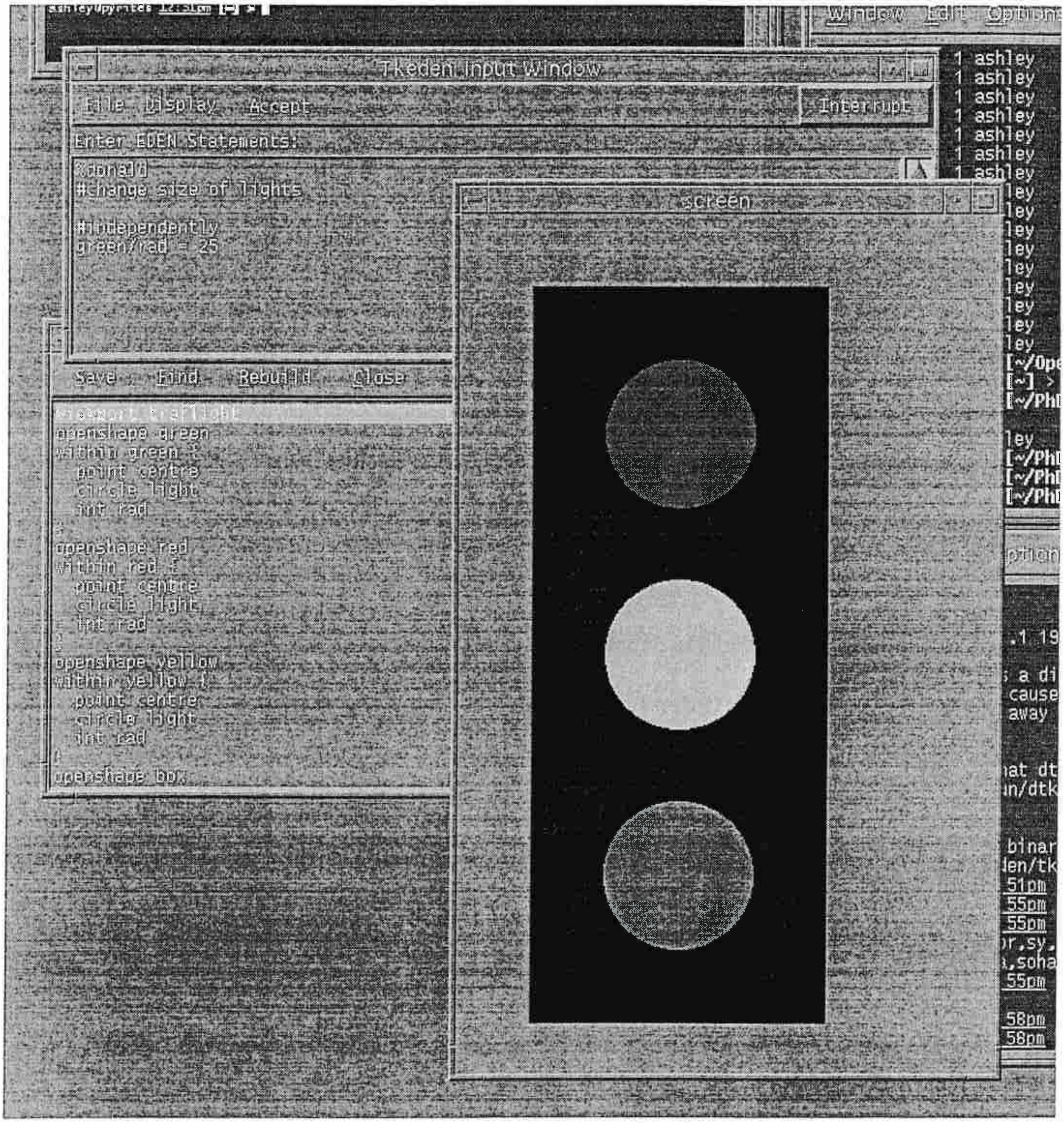
The use of a Definitive Script ("script of definitions") to represent state

Can conflate several perspectives on traffic lights, and represent them using a family of definitions

# typical definition:	*observable = function of observables*
# Traffic light designer (aesthetic)	
shape	lightR = circle(centreR, radiusR) lightY = circle(centreY, radiusY) lightG = circle(centreG, radiusG)
location	centreR = (x,y) centreY = (x, y-k) ...
colour	colourR = if red_on then RED else DARK ...
size	radiusR = 10 inches ...
# Driver at road junction	
colour pattern	red_on = if (phase is R or RY) then R_on else R_off yellow_on = if (phase is RY or Y) then Y_on else Y_off ....
phase of lights	light_sequence = [R, RY, G, Y] phase = light_sequence[index]
phase index (in range 1..4)	index = 1
traffic convention	status = ["stop", "ready to go", "go", "ready to stop"][index]
# Traffic light maintenance	
electrical components	bulbR = OK ... power = ON
voltages (in volts)	voltageR = if (power == ON) then 240 else 0 ....
currents (in amps)	currentR = voltageR / resistanceR ....
resistances (in ohms)	resistanceR = if bulbOK then K else infinite ....
status of components	R_on = (bulbR==OK) and (power==ON) ....

1-Agent Modelling

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Representation of roles

In so far as I can be simultaneously engaged in several overlapping contexts at the same moment it is appropriate to conflate observables from several different roles

For instance, I may be a traffic light repair man who happens to be a short-sighted driver approaching a traffic light that is malfunctioning: in such a context, relevant observables might include:

- the blurred visual image of the lights
- what I would be seeing if the lights were not blurred
- the inferred abstract state of the light (i.e. what lights are supposed to be lit)
- the status of the lights as in the traffic light sequence (i.e. I should stop etc)
- the expected electrical status of components (e.g. bulb failure, circuit failure).

Conflation of contexts is potentially a creative process e.g. essential to explanation of interaction

---

... parable conveniently combines story and projection. To understand parable is to understand root capacities of the everyday mind, and conversely.

Meanings ... are not mental objects bounded in conceptual spaces but rather complex operations of projecting, blending, and integrating over multiple spaces.

Turner: The Literary Mind (p5, p86)

For a causal account of what is being observed in relation to the traffic light, also need **separation of roles**

e.g. what are the responsibilities of the driver? what expectations have we of a driver?

Identify roles through the classification of observables (using the LSD notation)

oracles those observables that properly belong to my current role

as a driver, I am concerned with the pattern of colours
as an aesthetic designer, I am not concerned with the traffic light sequence

handles those observables over which I have conditional control

as an aesthetic designer, I can influence the colour, size, location of lights

derivates those indivisible patterns of correlated change I observe

a driver expects the pattern of illumination to reflect the phase indivisibly
an aesthetic designer may wish to switch the lights randomly & independently

protocol the rules that connect observed cues for action with potential response

too brief a green light for heavy traffic is a cue for a traffic light installer to increase the length of the green light in the light cycle

Causal accounts: introducing the 2nd person perspective

Contexts are organised around collections of observables resembling objects that have integrity "the cat", "the introduction to this text", "the table lamp"

In giving a causal account of a phenomenon in a context, am led to postulate agency similar to my own

See agents as mediating, and being explicable in terms of projection of agency "resembling my own" "I can read my script when the table lamp is switched on", "the computer saves my text automatically"

The coherence of my interaction empirically validates the identification and projection of agency

For instance, can conceive the traffic light itself as an agent: responding to its environment;

```
agent traffic light {

oracle      time_elapsed, time, car_waiting, phase

state       phase (R, RY, G, Y)
            red_lit, yellow_lit, green_lit
            time_on_R, time_on_G, time_in_transition
            time_of_last_change

derivate    red_lit = (phase==R) or (phase==RY)
            yellow_lit = (phase==RY) or (phase==Y)
            green_lit = (phase==G)
            time_elapsed = time - time_of_last_change

protocol    (phase==R) and car_waiting and time_elapsed > time_on_R
                      -> time_of_last_change =|time|; phase=RY,
            (phase==RY) and time_elapsed > time_in_transition
                      -> time_of_last_change = |time|; phase=G,
            (phase==Y) and time_elapsed > time_in_transition
                      -> time_of_last_change = |time|; phase=R,
            (phase==G) and time_elapsed > time_on_G
                      -> time_of_last_change =|time|; phase=R
}
```

Can interpret this as follows: metaphorically, it is as if a traffic light knows the time, knows the current phase of the lights, and can detect whether there is a car waiting (its oracle observables). There are certain observables bound to the traffic light in such a way that they would otherwise be meaningless: which of the red, green and yellow lights are lit, what phase the light is in, the time when it entered that phase, and what durations are programmed for the green and red light phases (its state observables). There are certain dependencies between the values of its state and oracle observables. There are certain cues to determine when it should enter a new phase.

Status of the Model of the Traffic Light

Observables include quantities that can't be directly observed

E.g. the behaviour of a traffic light is attributed to voltages, currents etc of which I have no experience

I have only artefacts (like animated circuit diagrams) to tell the story of how a traffic light operates and instruments (like voltmeters) to create experiential equivalents of putative conceptual quantities

Empirical evidence gives me sufficient justification for adopting a particular explanation
This explanation is effectively captured in an LSD account of the workings of the traffic light

The information about observables can be partial

car_waiting is at a high level of abstraction e.g. might be supplied by an optical sensor or switch in road

```
agent switch_in_road {

oracle      car_crosses_switch, time

state       car_waiting, time_to_clear_lights, time_crosses_switch

derivate    elapsed_time = time - time_crosses_switch

protocol    car_crosses_switch -> car_waiting = true; time_crosses_switch=|time|,
            elapsed_time > time_to_clear_lights -> car_waiting=false

}
```

This introduces issues to be addressed about operation of the switch
e.g. can car_waiting be set to false when there is no possibility of crossing the switch
cars go round a car that obstructs the switch,
cars queue up in such a way that a long time elapses since switch crossed

Modelling activity prompts imaginative speculation about scenarios that are not preconceived

In general, won't be able to automate from an LSD description: conflicts, ambiguities to be resolved

Execute protocols under super-agent control, even entirely under super-agent discretion

Reflects the extent to which implicit representation of ignorance is involved
What we *have* experienced shapes our expectations about what we have not experienced

Closed-world modelling is typically optimised to take advantage of what has been reliably experienced

Use the model to identify contexts, agents, dependencies, and to formulate hypotheses

Communicating from myself to another agent like myself

Empirical Modelling identifies primitive processes with 1st person activities: I assert that

"this experience is like this experience"

No-one else can experience this likeness as I experience it in the sense that my experience is divorced from your consciousness and vice versa

[cf the idea that logic provides the most primitive foundation for human activity]

There may be what empirically seems to be a corresponding likeness between two experiences of your own

I may construct an artefact specifically to represent some experience in this manner

It may be that this artefact serves a mediating role in leading you to apprehend what empirically seems to be a similar likeness between your own experiences

The personal validity of my representation of experiences by artefacts does not rely on this

e.g. a professional snooker player may use an idiosyncratic trick to align the cue for a particular shot

Mediation does not have to be via a commonly perceived artefact, can be invoked linguistically

cf "though I sang in my chains like the sea": where words can evoke the likeness

but two private experiences are necessary for the likeness to be apprehended

"singing in chains" as sense of protesting against being captive
"the sea singing in chains" as evoking the sound of breaking waves over pebbles

Communication between observers introduces intersubjectivity issues

cf the commonly accepted different nature of certain observables, such as traffic speed readings

cf the way in which mathematical models e.g. finite state machines, geometric references are used

Motivations for Empirical Modelling

Investigation of blends

Explanatory modelling, especially where misunderstanding or conflict is involved (e.g. accidents)

Identification of stable contexts

Designing behaviours for concurrent systems of agents

Supporting activities in which concurrent decision-making is involved

Enabling construction through experimentation and human intervention

Migration through different paradigms of knowledge represented in the Empiricist Perspective on Learning

Ways in which to organise and interpret the use of definitive scripts

A. 1-agent modelling

I act as a single agent, conflating roles where this is possible, slipping in and out of roles where appropriate. This presumes no adherence to a single context, nor concern for reflecting an external sequence of events. Gives scope for experimentation, creative processes, fantasising.
The transitions from script to script are unconstrained and I have arbitrary privileges to modify observables.

Can also use 1-agent modelling to explore particular roles in detail, such as driving past traffic lights.
In this context, the modelling is motivated by realism (cf VR), and the creation of convincing artefacts.

B. Modelling the interaction of many agents within a system from the perspective of one observer

I create a script as if I were an objective observer of the interactions between many agents.
I may be concerned with explanatory modelling, as in science or as in accident investigation.
This will involve projection of presumed states on to other agents.
Other relevant issues include: stimulus-response patterns, time-based behaviour, synchronisation.
(Simultaneous redefinition of observables is possible.)
Typically the transitions from script to script will presume a particular context for observation.
(Integrity needed to guarantee that there is a system, and analysis of the system prescribes observations.)
cf the role of the traffic police monitor, which limits the interpretations of responsibility and agency, and presumes the relevance and authenticity of particular observations and procedures.

A particularly useful application for this mode of modelling involves giving complete discretion over state transitions to the external observer. This discretion can be used in several ways:

- to play the roles of the agents within the system
  e.g. I might take on the role of changing the traffic lights
- to arbitrate where the outcome of singular events is uncertain
  e.g. I might decide what outcome to presume where two cars collide
- to simulate failures and malfunction of the system
  e.g. I might wish to investigate the consequences of lights failure, or speedier changes
- to carry out controlled experiments, possibly on subcomponents of the system
  e.g. to explore what is a reasonable model for stopping distances in bad weather.

C. Modelling phenomena from the perspectives of several different observers / system designers

The modelling activity is carried out in a distributed environment.
e.g. the roles of the agents concerned with traffic lights are represented by scripts on different workstations.
Conceptually simplest way to accommodate the idiosyncratic observer who is not "in touch with reality".

The most significant aspect of this modelling activity is the management of views.
This can serve many functions:

- establishing coherence amongst perspectives of many designers (concurrent engineering)
- providing a forum for discussion between viewpoints (dialectic)
- providing a framework for integrating private and public activities
- providing a setting for studying administrative strategies and business processes
- representing the diversity of different viewpoints (post-modernism).

3. Illustrative Case Studies in Empirical Modelling

3.1. The traffic light case study and the Empiricist Perspective on Learning

Traffic light model can be used as a case-study with reference to

locations / colour of lights
interpretation of light pattern
sequence of lights: expectations
synchronisation of views: crossing traffic
statistical analysis
simulation of driving past traffic lights

Model 1a: Perception of the traffic light

construct script for light display
change size(s) of lights, together / independently
modify colour/intensity of lights, and of background
simulate different lighting conditions, degrees of colour blindness
change orientation, location of lights

switch lights off/on independently
simulate changes in current

Model can be used to explore aspects of the subjective way the lights can be perceived

Model 1b: Psychedelic experiences of the traffic lights

size of lights is subject to variation
location of lights changes
the lights are seen double
face appears on a light
lights operate as buttons that come on and off as pressed

Model can be used to highlight penumbra of neighbouring perceptions, not preconceived

Model 2a: Perception of behaviour - physical aspect

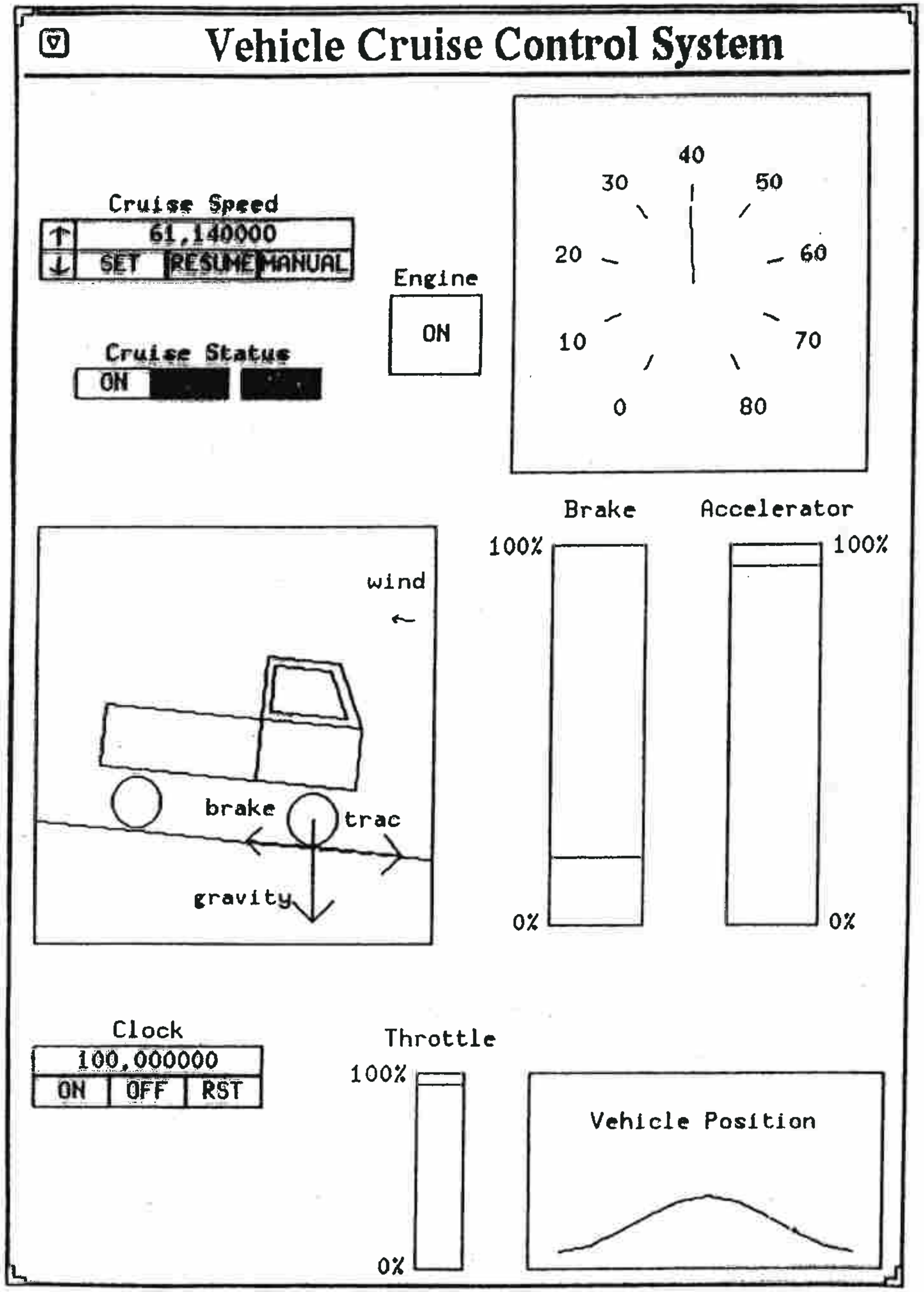
introduce time and observe behaviour of lights over time
random illumination model
orthodox sequence, abnormally fast
behaviours wth malfunction of lights: e.g. stuck on / off

Model can be used to explore the perception of patterns of state-change over time

Model 2b: Perception of behaviour - cultural aspect

abstract point in the lights cycle as observable
identification of abstract point in cycle whilst malfunction
conventional interpretation as observable (red = stop etc)

Model can be used to expose the cultural component in perception of state, role of memory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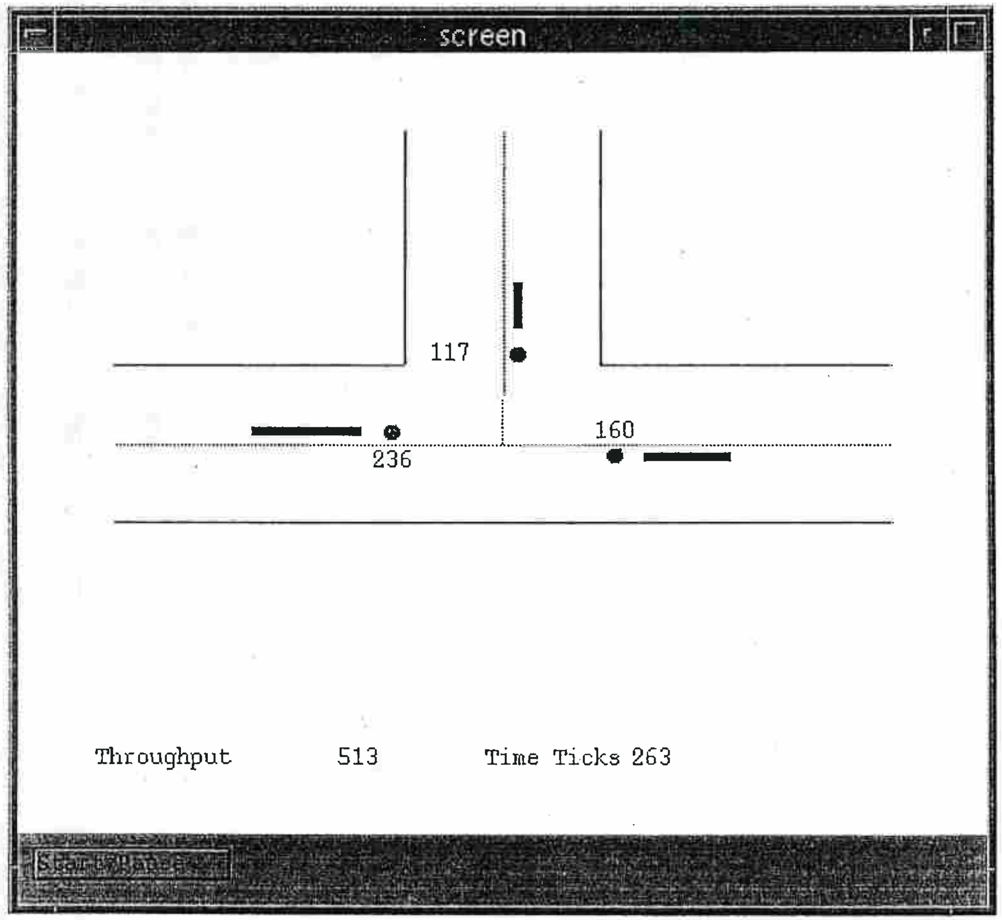
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Model 3a: Lights in context - personal experience

combine lights with a car driving simulation - an artefact to represent car and road
synchronisation of driver responses with behaviour of lights
environmental factors: obstruction on the road, faulty lights, different stoppping distances, fog
timing characteristics of lights varied
prioritisation of response to lights: as when obstruction, or lights stuck on red
change the conventions of the switching sequence

Model places the perception of a traffic light by a single road user in stimulus-response context

Model 3b: Lights in context - shared experience

introduce more than one driver
commonality of the environment explored
synchronisation of the traffic light states explored
introduce optical sensor to model
investigate automation of the car driver's role

Model can be used to explore issues of intersubjectivity and assumptions about environment

Model 4: Integration with models made from other perspectives

combine with a traffic light simulation based on an objective view of an external observer
analyse the timing of the lights from a statistical standpoint
supply a model for the electrical circuitry
can then (e.g.) interpret failures of the electrical circuit in terms of manifest behaviours

Model can be used for explanatory purposes, and to identify "neighbouring" system behaviours

Key point of Empirical Modelling principles
... all these models can be developed
- in a single environment and in one conceptual modelling activity
- without preconception about what limits are set on the range of interpretations
- in an incremental manner with scope for interactive retrospective revision.

Traffic light case study illustrates **"The Empiricist Perspective on Learning"**

Empiricist Perspective
- not prescriptive about learning process nor model construction method
- framework for representing many varieties of knowledge
- framework for supporting different teaching strategies
- framework for many different explanatory models

3.2. Other case studies

a. Modelling a historic railway accident
b. Developing and presenting the heapsort algorithm
c. Constructing a virtual electrical laboratory
d. Animal behaviour model

For more information and many further examples, see also: **http://www.dcs.warwick.ac.uk/modelling/**

Experiential Framework for

An Empiricist Perspective on Learning

private experience / empirical / experiential

interaction with artefacts:
identification of persistent features and contexts

practical knowledge:
correlations between artefacts, acquisition of skills

identification of dependencies
and postulation of independent agency

identification of generic patterns of interaction
and stimulus-response mechanisms

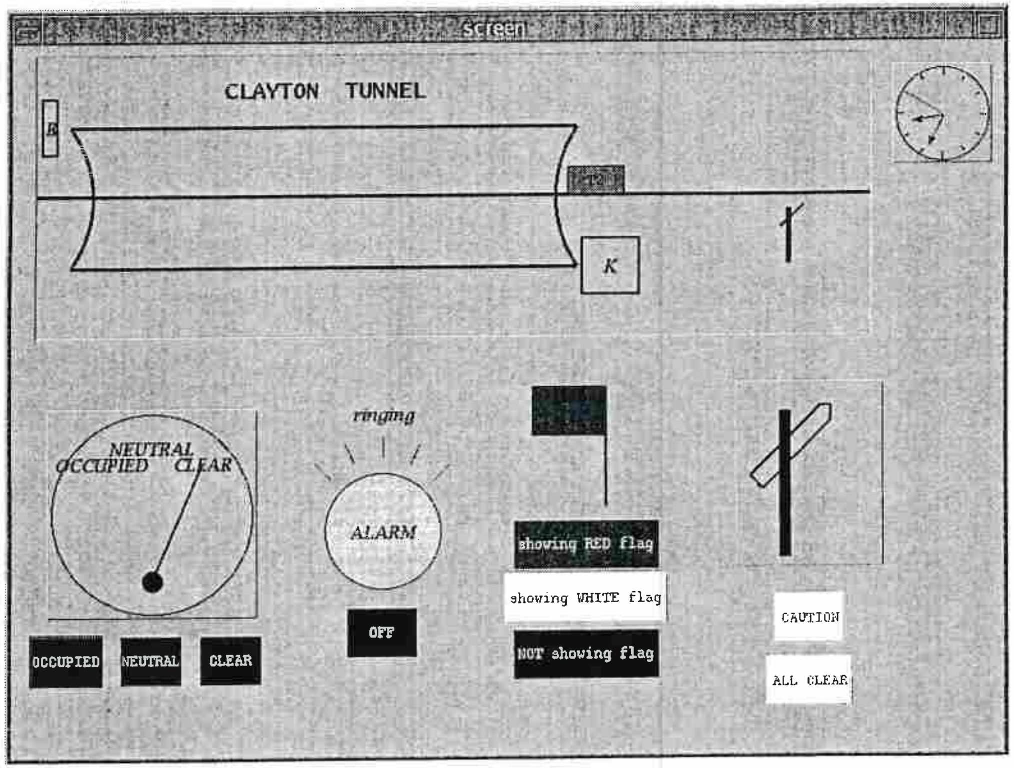
non-verbal communication
through interaction in a common environment

phenomenological uses of language

identification of common experience and objective knowledge

symbolic representations and formal languages:
public conventions for interpretation

public knowledge / theoretical / formal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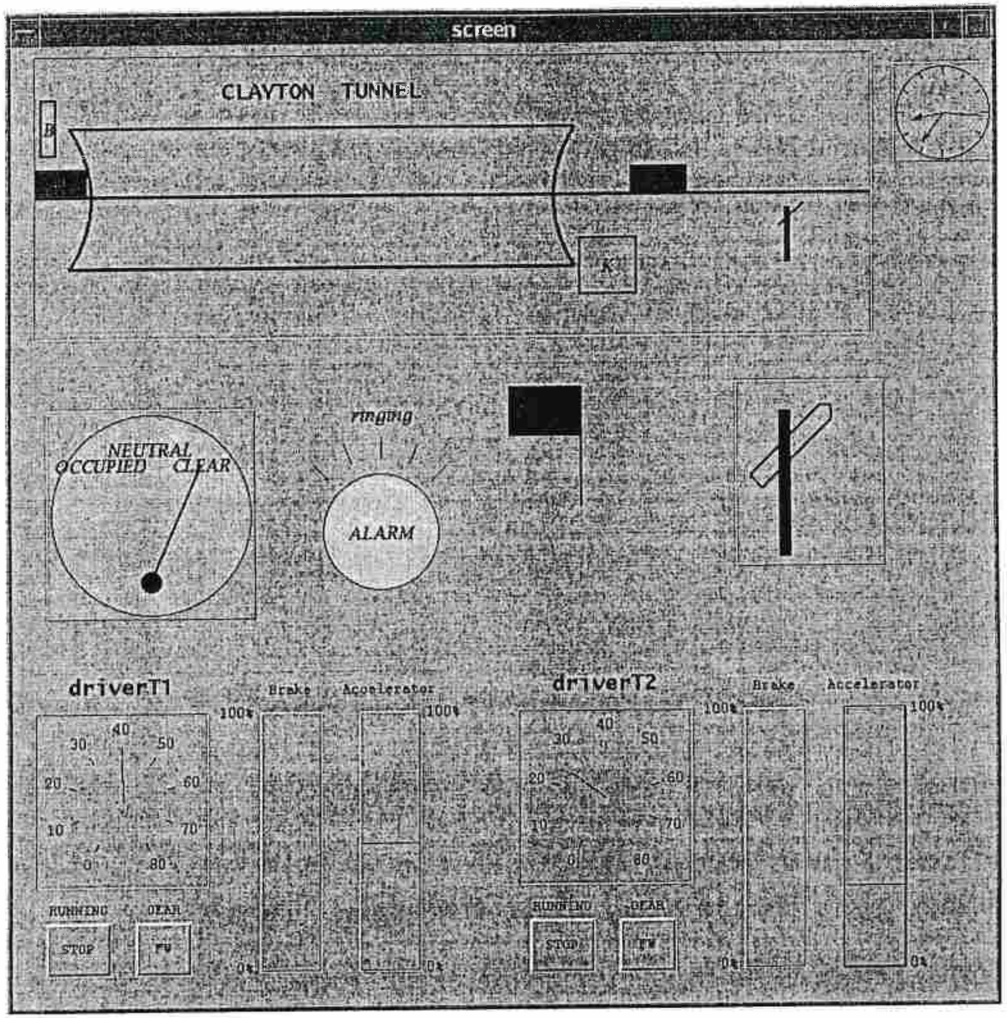
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19	13	4	8	1	32	3	12	21	11	18	11	18	15	5	20	5	18	9	28	27	27	29	19	17	5	21	22	8	3	26

Figure 1: Unsorted array of elements

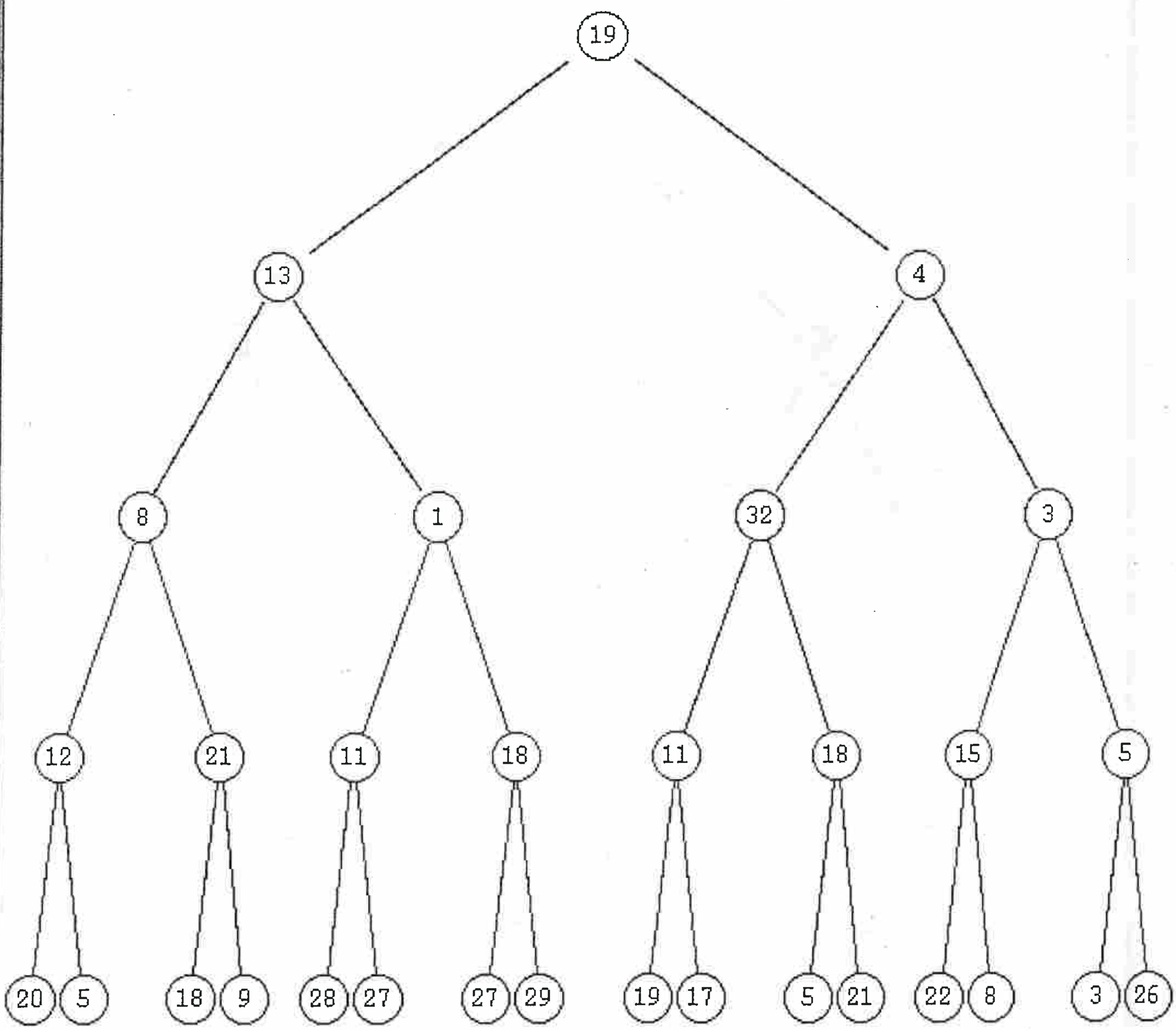

Figure 2: Heap representation for the array in Figure 1

screen

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Figure 1: Unsorted array of elements

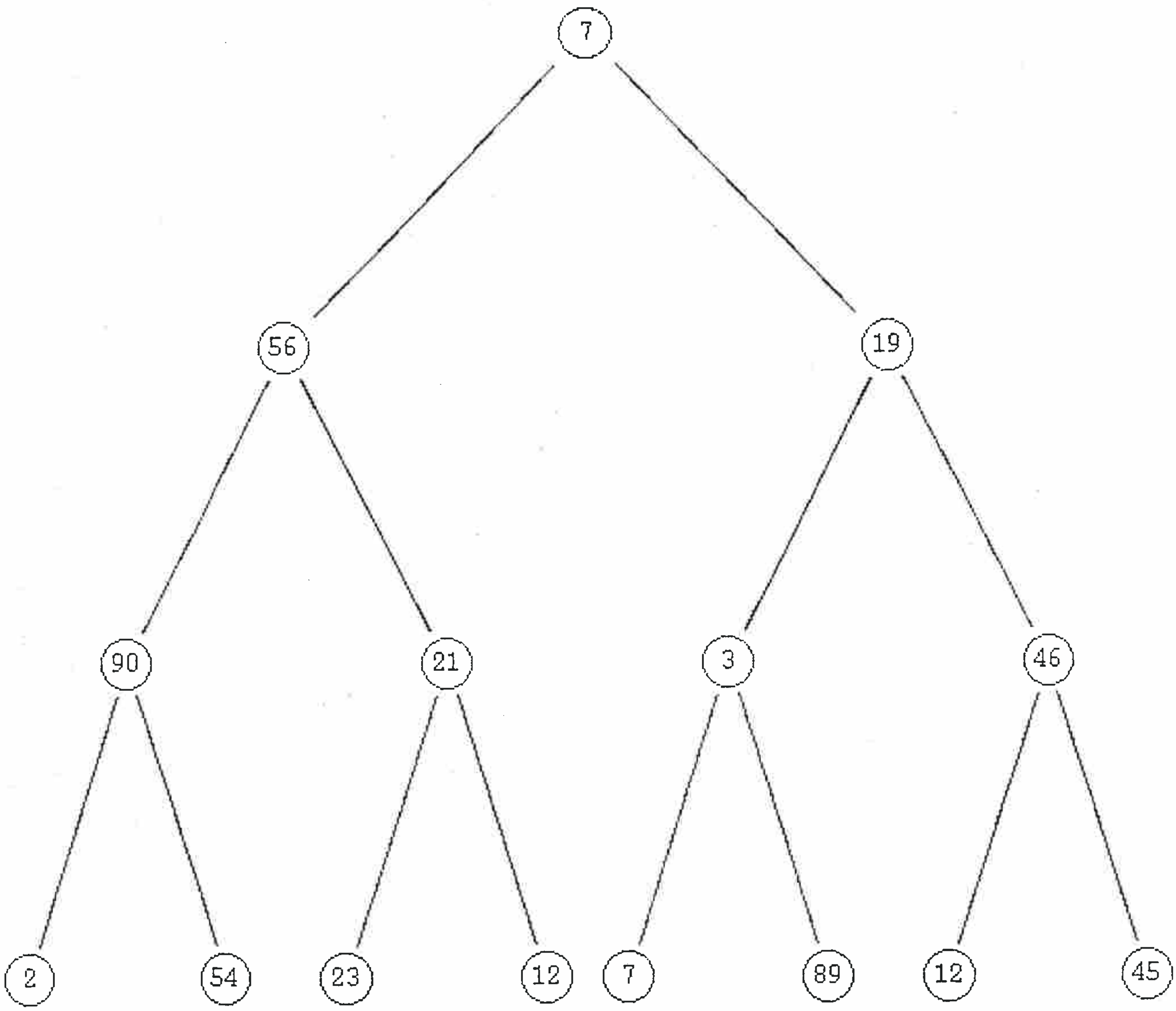
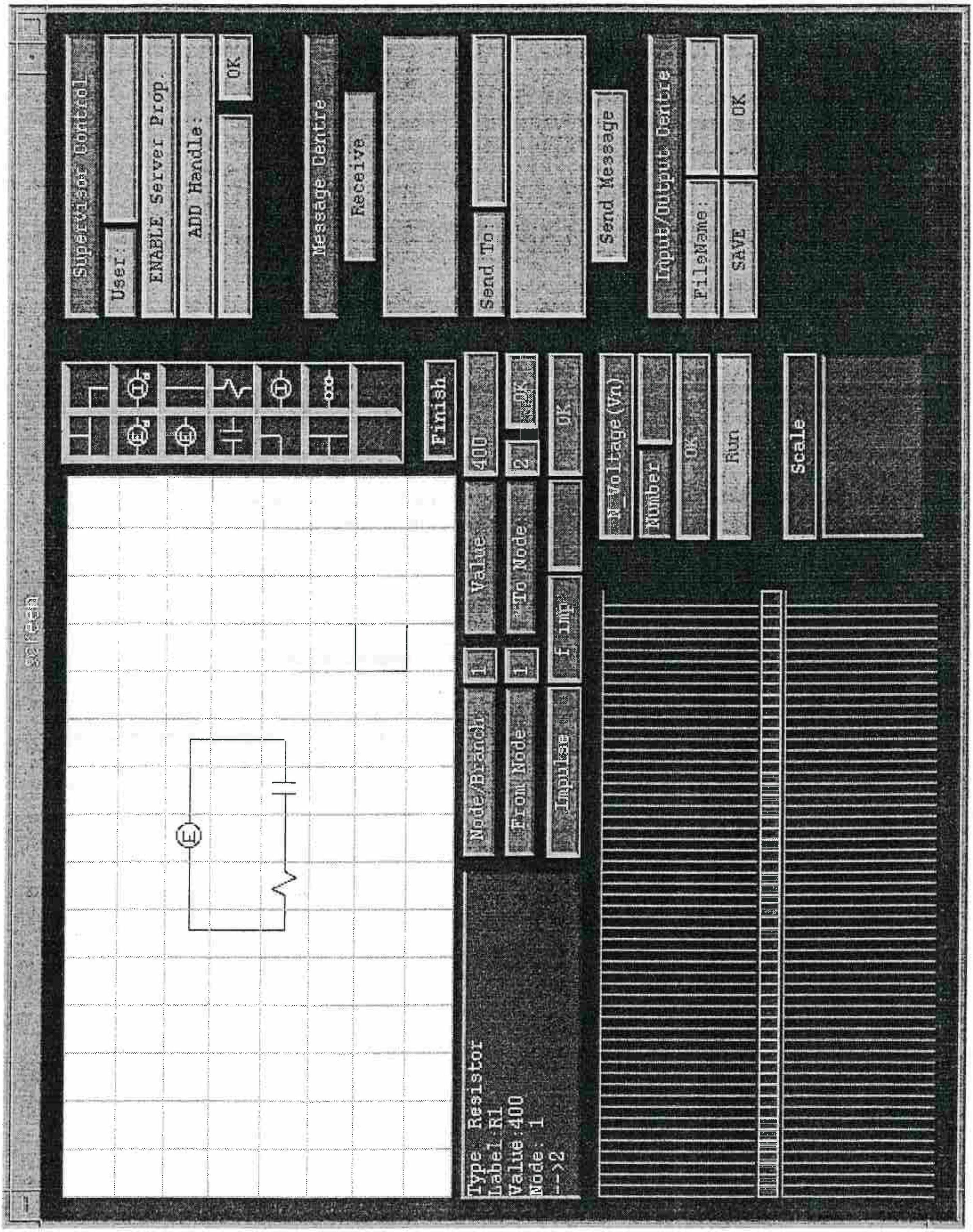


Figure 2: Heap representation for the array in Figure 1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Conclusions

Computer Science
- providing a broader foundation than the classical theory of computation

Mathematics
- connections with history of mathematics, especially pre-19th century variable concept
- complementing the formalist emphasis in mathematics: visualisation and experiment
- pedagogical implications concerned with experiential approaches

Physics
- bridging experimental and theoretical physics perspectives
- subjective physics
- the relevance and role of the observer

Engineering
- conceptual design
- concurrent engineering
- bridging the empirical and theoretical aspects

English
- modelling for play direction and construction, both technical and artistic
- modelling situations from perspectives of characters in a novel
- specifying the semi-formal rules of grammar or scansion

History
- reconstruction of historical events
- distributed environments for investigating conflicting interpretations

Business
- pre-existing culture and related software development: spreadsheets, decision support systems
- business process re-engineering

Economics
- alternatives to closed-world mathematical models for finance and economic trends

Psychology
- enfranchising a less formal view of psychology as a scientific discipline
- constructing models of perception and behaviour

Education
- new medium for communication, making environments used in discovery and scholarship accessible

Significance of informal and non-verbal

V Axline

role of non-verbal interaction in psychotherapy

Richard Feynman

physical understanding - unmathematical, imprecise, inexact - absolutely necessary for the physicist

David Gooding

construals in the work of Faraday

Fred Brooks

essence of software is in the requirements capture and specification process

William James

truth of our mental operations as an intra-experiential affair

Thesis behind principles of Empirical Modelling

Appropriate use of computer-based technology liberates the design and construction of artefacts

The scientist has a lot of experience with ignorance and doubt and uncertainty, and this experience is of very great importance, I think. When a scientist doesn't know the answer to a problem, he is uncertain. And when he is pretty darn sure of what the result is going to be, he is still in some doubt. We have found it of paramount importance that in order to progress we must recognise our ignorance and leave room for doubt. Scientific knowledge is a body of statements of varying degrees of certainty - some most unsure, some nearly sure, but none absolutely certain.

Richard Feynman (cited in a letter to the Guardian)

The Conflict between two Engineering Cultures

The **closed world** paradigm

... all real-world phenomena, the properties and relations of its objects, can ultimately, and at least in principle, be transformed by human cognition into objectified, explicitly stated, propositional knowledge.

The **open development** paradigm

..... contests the completeness of this knowledge

.....

..... assumes the primary existence of *practical experience*, a body of tacit knowledge grown with a person's acting in the world. This can be transformed into explicit theoretical knowledge under specific circumstances and to a principally limited extent only

.....

..... human interaction with the environment unfolds a dialectic of form and process through which practical experience is partly formalized and objectified as language, tools or machines (i.e. form) the use of which, in turn, produces new experience (i.e. process) as basis for further objectification.

P. Brödner: a German expert on Production Systems

=> study relationship between **empirical** and **theoretical**

An Empiricist Perspective on Learning

private experience / empirical / experiential

interaction with artefacts:
identification of persistent features and contexts

practical knowledge:
correlations between artefacts, acquisition of skills

identification of dependencies
and postulation of independent agency

identification of generic patterns of interaction
and stimulus-response mechanisms

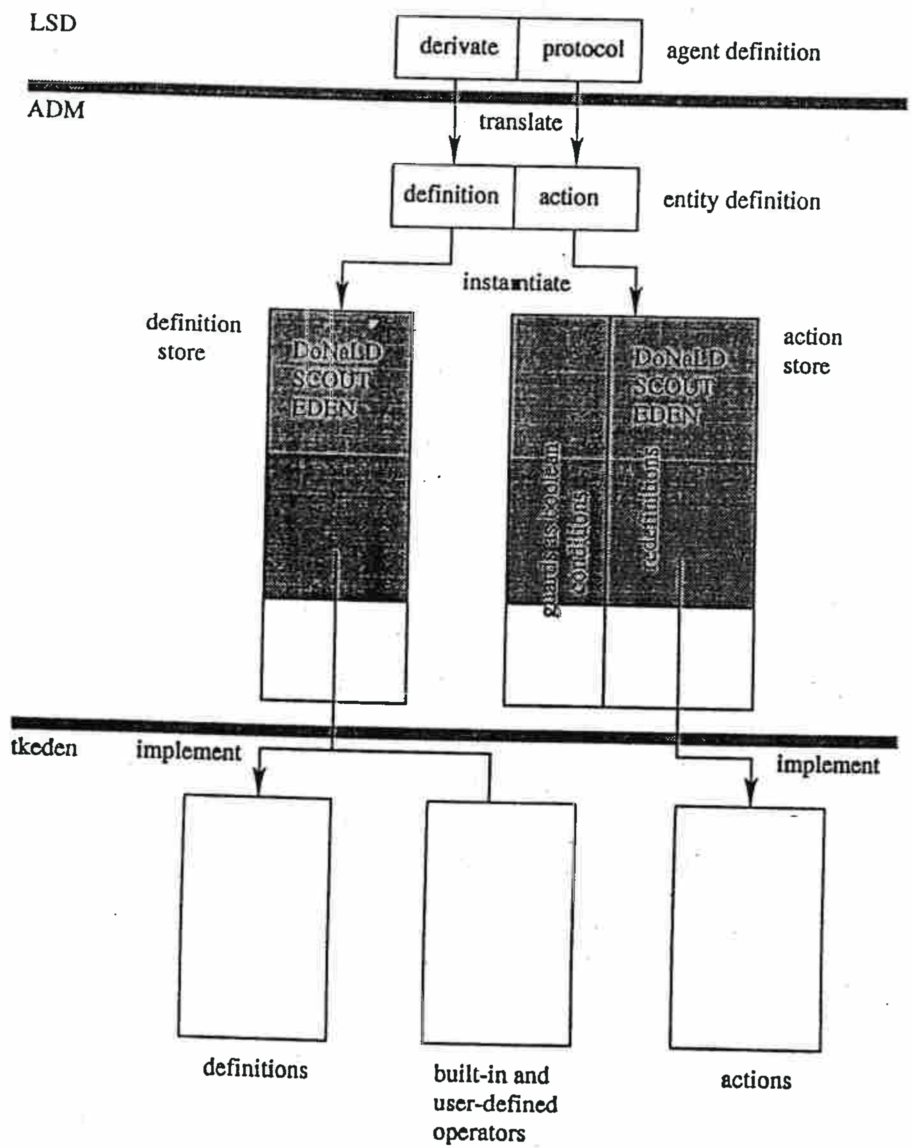
non-verbal communication
through interaction in a common environment

phenomenological uses of language

identification of common experience and objective knowledge

symbolic representations and formal languages:
public conventions for interpretation

public knowledge / theoretical / formal



Academic Staff Development session
Nov 4th 1998 WMB + SBK