HUMAN-COMPUTER INTERACTION THIRD EDITION DIX FINLAY ABOWD BEALE

chapter 17

models of the system

Models of the System

Standard Formalisms
software engineering notations used to specify the required behaviour of specific interactive systems

Interaction Models
special purpose mathematical models of interactive systems used to describe usability properties at a generic level

Continuous Behaviour
activity between the events, objects with continuous motion, models of time

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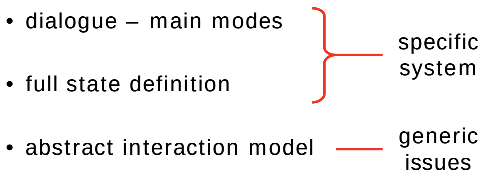
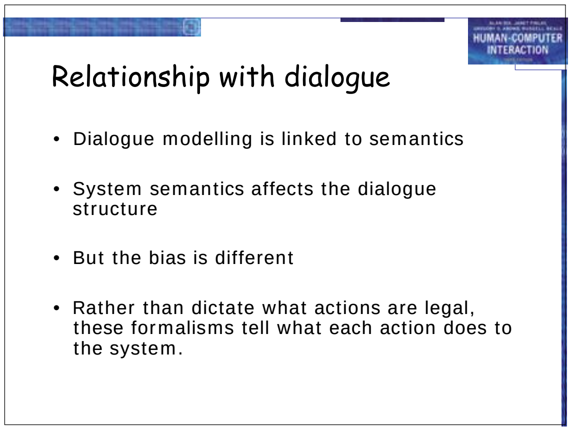
types of system model



- dialogue – main modes
- full state definition
- abstract interaction model

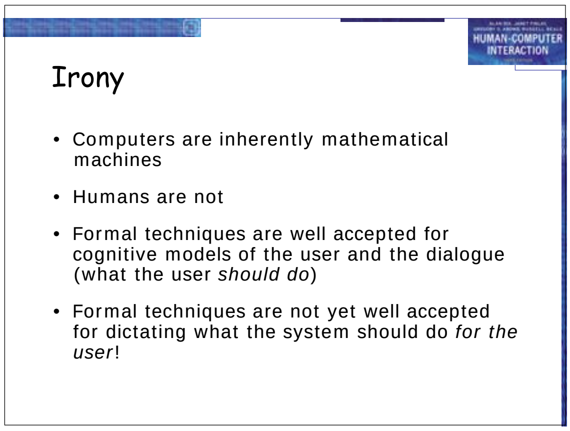
specific system

generic issues



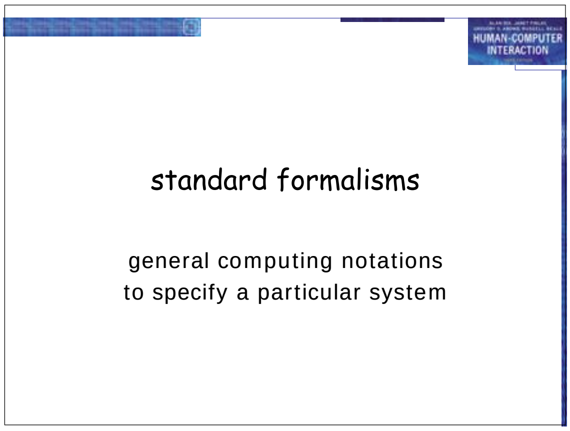
Relationship with dialogue

- Dialogue modelling is linked to semantics
- System semantics affects the dialogue structure
- But the bias is different
- Rather than dictate what actions are legal, these formalisms tell what each action does to the system.



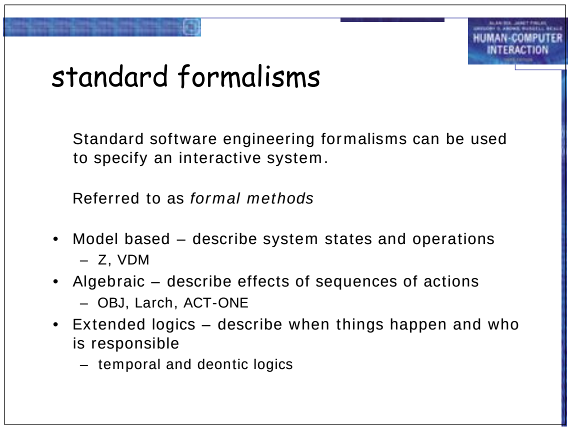
Irony

- Computers are inherently mathematical machines
- Humans are not
- Formal techniques are well accepted for cognitive models of the user and the dialogue (what the user *should do*)
- Formal techniques are not yet well accepted for dictating what the system should do *for the user*!



standard formalisms

general computing notations
to specify a particular system

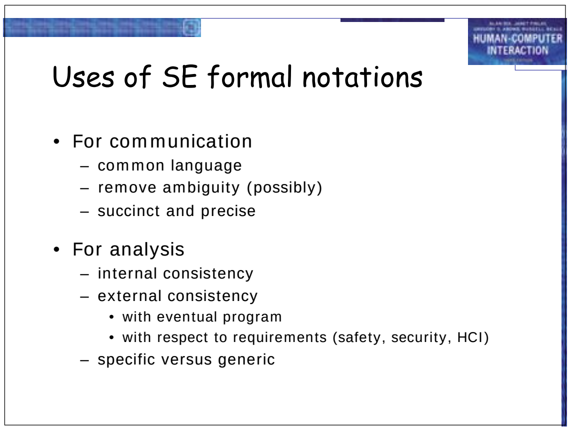


standard formalisms

Standard software engineering formalisms can be used to specify an interactive system.

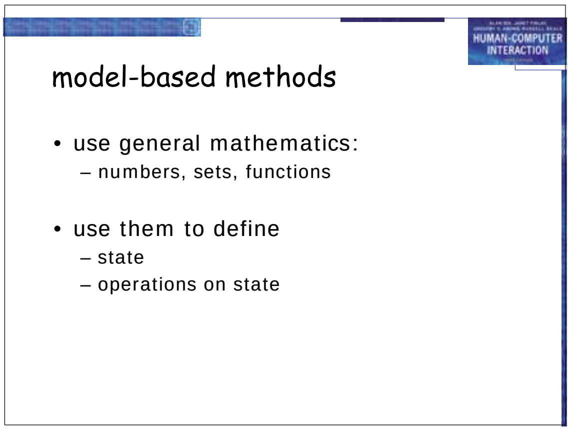
Referred to as *formal methods*

- Model based – describe system states and operations
  - Z, VDM
- Algebraic – describe effects of sequences of actions
  - OBJ, Larch, ACT-ONE
- Extended logics – describe when things happen and who is responsible
  - temporal and deontic logics



Uses of SE formal notations

- For communication
  - common language
  - remove ambiguity (possibly)
  - succinct and precise
- For analysis
  - internal consistency
  - external consistency
    - with eventual program
    - with respect to requirements (safety, security, HCI)
  - specific versus generic



model-based methods

- use general mathematics:
  - numbers, sets, functions
- use them to define
  - state
  - operations on state

model-based methods

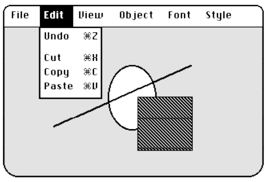
- describe state using variables
- types of variables:
  - basic type:
    x: Nat – non-negative integer {0,1,2,...}
    or in the Z font: $\mathbb{N}$
  - individual item from set:
    shape_type: {line, ellipse, rectangle}
  - subset of bigger set:
    selection: **set** Nat – set of integers
    or in the Z font: $\mathbb{P}\,\mathbb{N}$
  - function (often finite):
    objects: Nat → Shape_Type

Mathematics and programs

Mathematical counterparts to common programming constructs

Programming	Mathematics
types	sets
basic types	basic sets
constructed types	constructed sets
records	unordered tuples
lists	sequences
functions	functions
procedures	relations

running example …



a simple graphics drawing package
supports several types of shape

define your own types

an x,y location is defined by two numbers

Point == Nat × Nat

a graphic object is defined by its shape, size, and centre

Shape ==

shape:	{line, ellipse, rectangle}	
x, y:	Point	– position of centre
wid:	Nat	
ht:	Nat	– size of shape

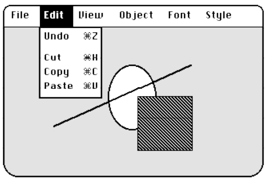
… yet another type definition

A collection of graphic objects can be identified by a ‘lookup dictionary’

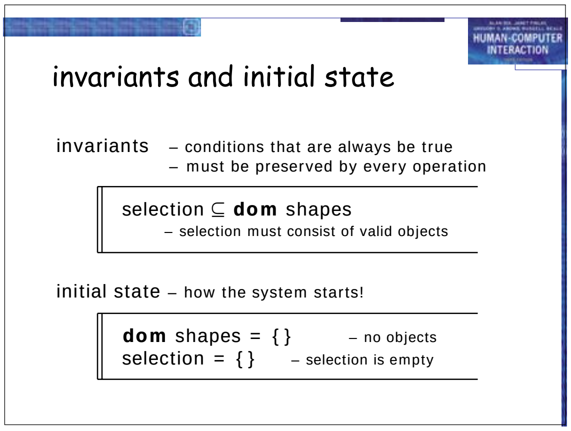
[Id]
Shape_Dict == Id ⇸ Shape

- Id is an introduced set
  - some sort of unique identifier for each object
- Shap_Dict is a function
  - for any Id within its domain (the valid shapes) it gives you a corresponding shapthis means for any

use them to define state



shapes:	Shape_Dict	
selection:	**set** Id	– selected objects



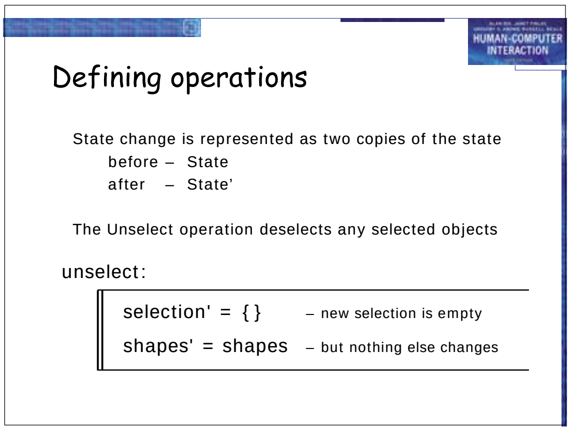
invariants and initial state

invariants – conditions that are always be true
– must be preserved by every operation

selection $\subseteq$ **dom** shapes
– selection must consist of valid objects

initial state – how the system starts!

dom shapes = { } – no objects
selection = { } – selection is empty



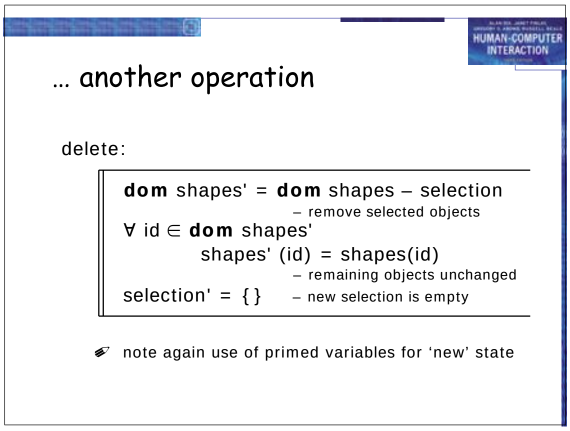
Defining operations

State change is represented as two copies of the state
before – State
after – State'

The Unselect operation deselects any selected objects

unselect:

selection' = { } – new selection is empty
shapes' = shapes – but nothing else changes



… another operation

delete:

dom shapes' = **dom** shapes – selection
– remove selected objects
$\forall$ id $\in$ **dom** shapes'
shapes' (id) = shapes(id)
– remaining objects unchanged
selection' = { } – new selection is empty

✐ note again use of primed variables for 'new' state

display/presentation

- details usually very complex (pixels etc.)
  … but can define **what** is visible

```
Visible_Shape_Type =  | Shape_Type
                      | highlight:  Bool
```

display:

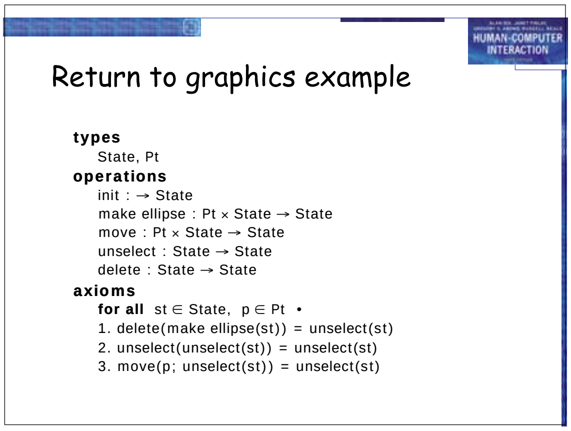
```
| vis_objects:   set Visible_Shape_Type
|--------------------------------------
| vis_objects =
|      { ( objects(id), sel(id) ) | id ∈ dom objects }
|   where   sel(id ) =  id ∈ selection
```

Interface issues

- Framing problem
  - everything else stays the same
  - can be complicated with state invariants
- Internal consistency
  - do operations define any legal transition?
- External consistency
  - must be formulated as theorems to prove
  - clear for refinement, not so for requirements
- Separation
  - distinction between system functionality and presentation is not explicit

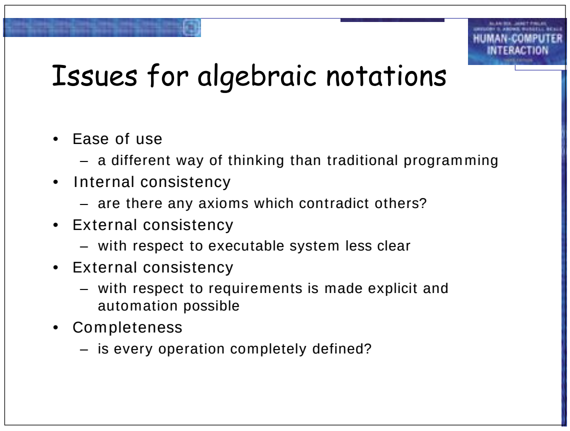
Algebraic notations

- Model based notations
  - emphasise constructing an explicit representations of the system state.
- Algebraic notations
  - provide only implicit information about the system state.
- Model based operations
  - defined in terms of their effect on system components.
- Algebraic operations
  - defined in terms of their relationship with the other operations.



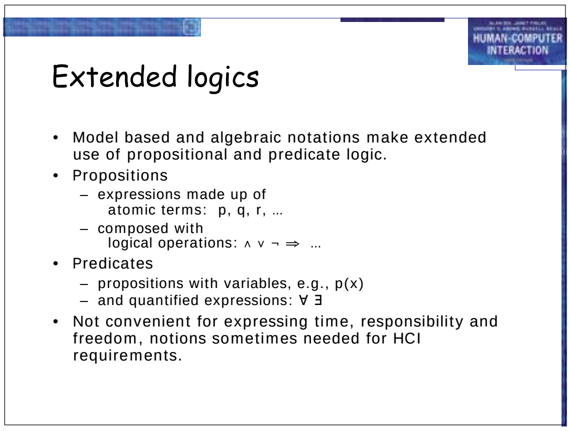
Return to graphics example

types
  State, Pt
operations
  init : → State
  make ellipse : Pt × State → State
  move : Pt × State → State
  unselect : State → State
  delete : State → State
axioms
  for all st ∈ State, p ∈ Pt •
  1. delete(make ellipse(st)) = unselect(st)
  2. unselect(unselect(st)) = unselect(st)
  3. move(p; unselect(st)) = unselect(st)



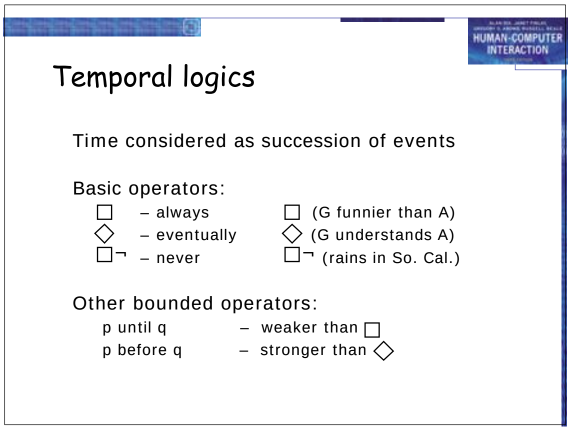
Issues for algebraic notations

- Ease of use
  - a different way of thinking than traditional programming
- Internal consistency
  - are there any axioms which contradict others?
- External consistency
  - with respect to executable system less clear
- External consistency
  - with respect to requirements is made explicit and automation possible
- Completeness
  - is every operation completely defined?



Extended logics

- Model based and algebraic notations make extended use of propositional and predicate logic.
- Propositions
  - expressions made up of
    atomic terms: p, q, r, …
  - composed with
    logical operations: ∧ ∨ ¬ ⇒ …
- Predicates
  - propositions with variables, e.g., p(x)
  - and quantified expressions: ∀ ∃
- Not convenient for expressing time, responsibility and freedom, notions sometimes needed for HCI requirements.



Temporal logics

Time considered as succession of events

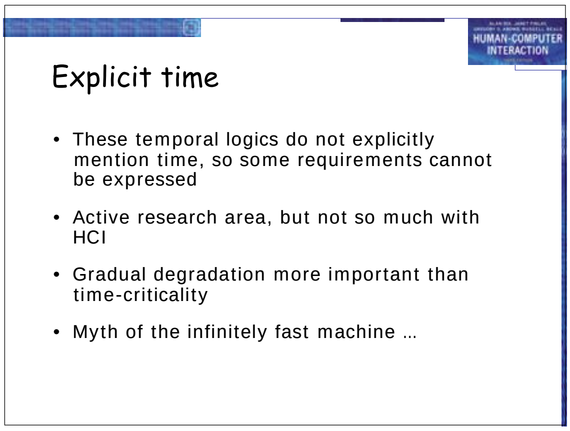
Basic operators:

$\Box$	– always	$\Box$	(G funnier than A)
$\Diamond$	– eventually	$\Diamond$	(G understands A)
$\Box\neg$	– never	$\Box\neg$	(rains in So. Cal.)

Other bounded operators:

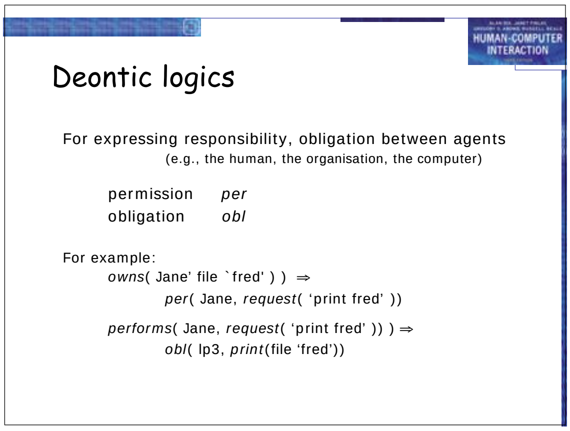
p until q – weaker than $\Box$

p before q – stronger than $\Diamond$



Explicit time

- These temporal logics do not explicitly mention time, so some requirements cannot be expressed
- Active research area, but not so much with HCI
- Gradual degradation more important than time-criticality
- Myth of the infinitely fast machine …



Deontic logics

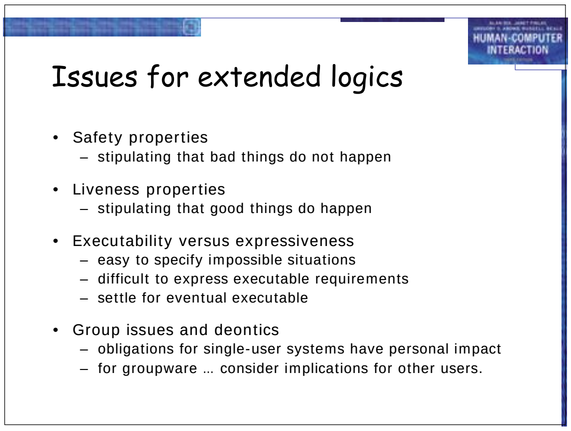
For expressing responsibility, obligation between agents
(e.g., the human, the organisation, the computer)

permission *per*
obligation *obl*

For example:

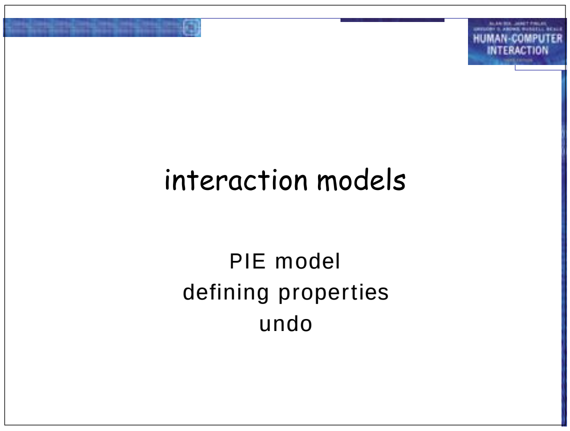
owns(Jane' file `fred')) ⇒
per(Jane, *request*('print fred'))

performs(Jane, *request*('print fred'))) ⇒
obl(lp3, *print*(file 'fred'))



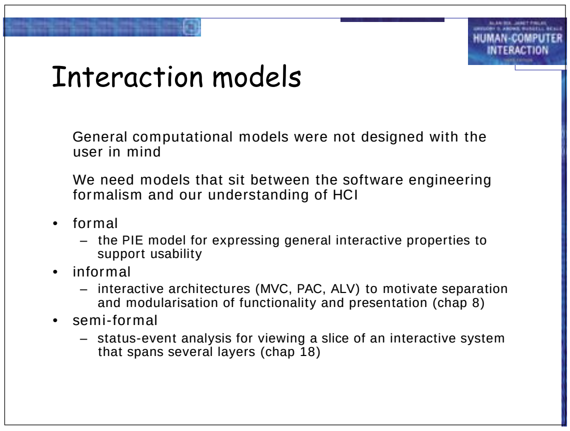
Issues for extended logics

- Safety properties
  - stipulating that bad things do not happen
- Liveness properties
  - stipulating that good things do happen
- Executability versus expressiveness
  - easy to specify impossible situations
  - difficult to express executable requirements
  - settle for eventual executable
- Group issues and deontics
  - obligations for single-user systems have personal impact
  - for groupware … consider implications for other users.



interaction models

PIE model
defining properties
undo

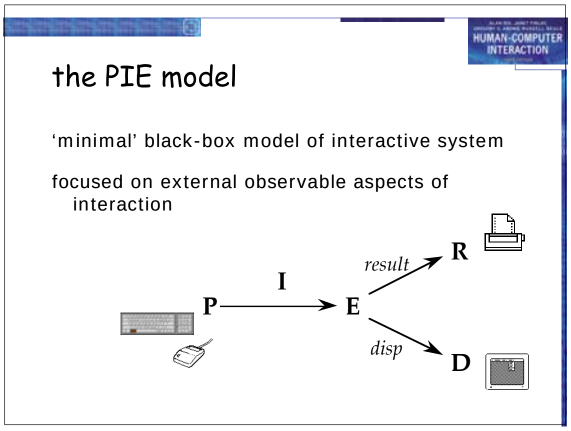


Interaction models

General computational models were not designed with the user in mind

We need models that sit between the software engineering formalism and our understanding of HCI

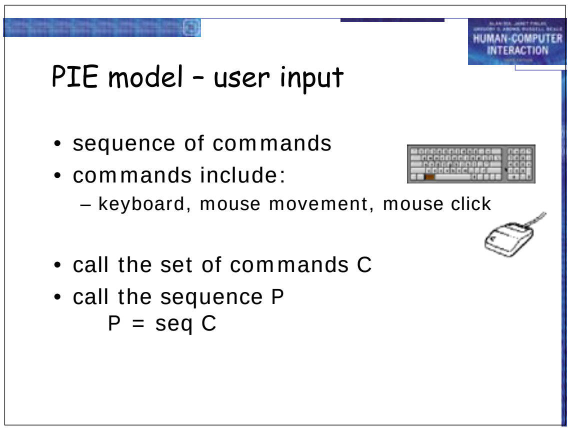
- formal
  - the PIE model for expressing general interactive properties to support usability
- informal
  - interactive architectures (MVC, PAC, ALV) to motivate separation and modularisation of functionality and presentation (chap 8)
- semi-formal
  - status-event analysis for viewing a slice of an interactive system that spans several layers (chap 18)



the PIE model

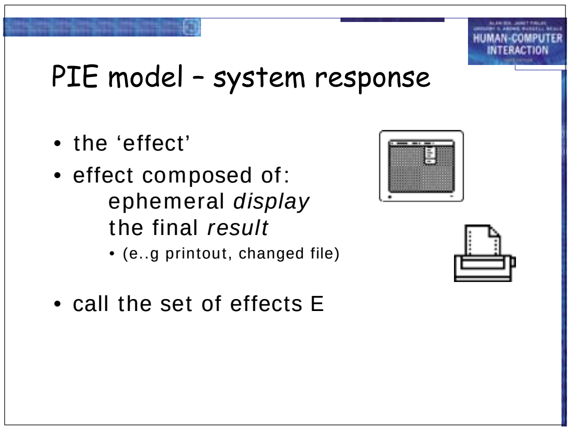
‘minimal’ black-box model of interactive system

focused on external observable aspects of interaction



PIE model – user input

- sequence of commands
- commands include:
  - keyboard, mouse movement, mouse click
- call the set of commands C
- call the sequence P
  P = seq C

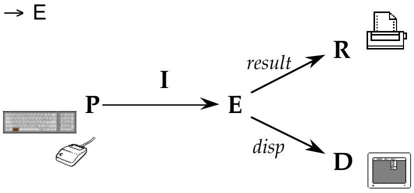


PIE model – system response

- the ‘effect’
- effect composed of:
  ephemeral *display*
  the final *result*
  - (e..g printout, changed file)
- call the set of effects E

PIE model – the connection

- given any history of commands (P)
- there is some current effect
- call the mapping the interpretation (I)
  I: P → E



More formally

[C;E;D;R]
P == seq C

I : P → E
display : E → D
result : E → R

Alternatively, we can derive a state transition function from the PIE.

doit : E × P → E

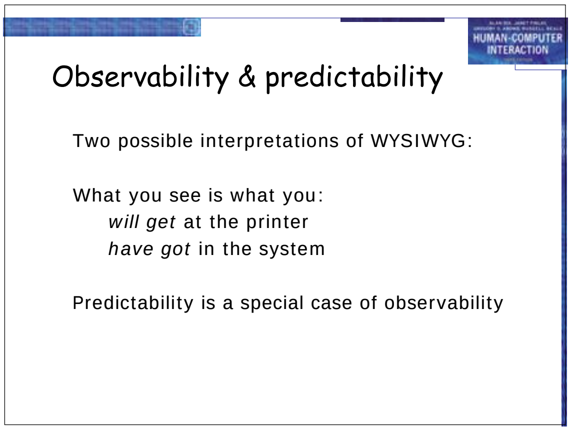
doit(I(p), q) = I(p q)
doit(doit(e, p). q) = doit(e, p q)

Expressing properties

WYSIWYG (what you see is what you get)
  - What does this really mean, and how can we test product X to see if it satisfies a claim that it is WYSIWYG?

Limited scope general properties which support WYSIWYG

- Observability
  - what you can tell about the current state of the system from the display
- Predictability
  - what you can tell about the future behaviour

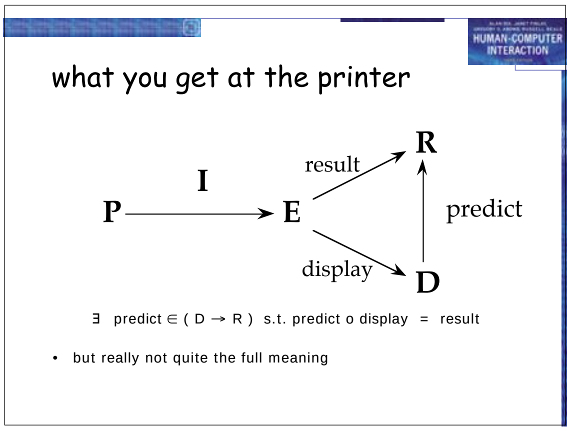


Observability & predictability

Two possible interpretations of WYSIWYG:

What you see is what you:
  will get at the printer
  have got in the system

Predictability is a special case of observability

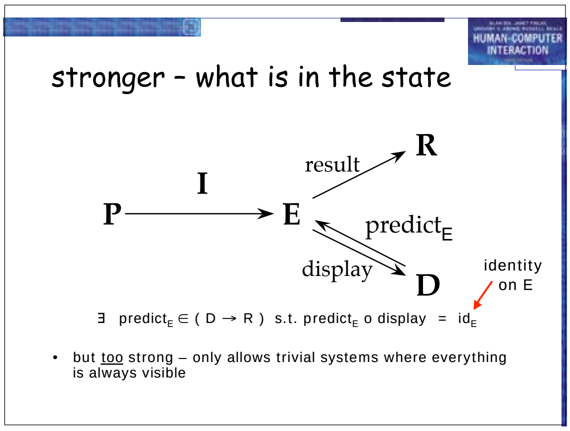


what you get at the printer

$$\begin{tikzcd} & & R \\ P \arrow[r, "I"] & E \arrow[ur, "result"] \arrow[dr, "display"'] & \\ & & D \arrow[uu, "predict"'] \end{tikzcd}$$

$\exists \ predict \in (D \rightarrow R) \ \text{s.t.} \ predict \circ display = result$

- but really not quite the full meaning



stronger – what is in the state

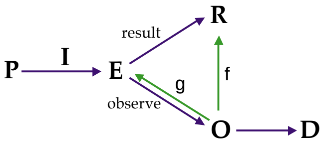
$$\begin{tikzcd} & & R \\ P \arrow[r, "I"] & E \arrow[ur, "result"] \arrow[dr, shift left, "display"'] & \\ & & D \arrow[ul, shift left, "predict_E"'] \end{tikzcd}$$

identity on E

$\exists \ predict_E \in (D \rightarrow R) \ \text{s.t.} \ predict_E \circ display = id_E$

- but <u>too</u> strong – only allows trivial systems where everything is always visible

Relaxing the property



- O – the things you can indirectly observe in the system through scrolling etc.
- predict the result
  $\exists\ f \in (O \rightarrow R)$ s.t. $f \circ observe = result$
- or the effect
  $\exists\ g \in (O \rightarrow R)$ s.t. $g \circ observe = id_E$

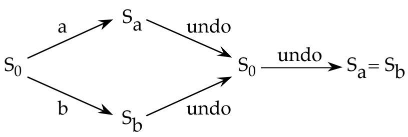
Reachability and undo

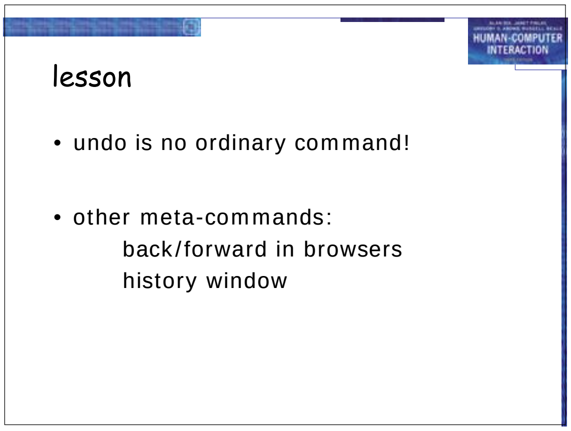
- Reachability – getting from one state to another.
  $\forall\ e, e' \in E \bullet \exists\ p \in P \bullet doit(e, p) = e'$
- Too weak
- Undo – reachability applied between current state and last state.
  $\forall\ c \in C \bullet doit(e, c\ undo) = e$
- Impossible except for very simple system with at most two states!
- Better models of *undo* treat it as a special command to avoid this problem

proving things - undo

$\forall\ c :\ c\ undo \sim null$?

only for $c \neq undo$

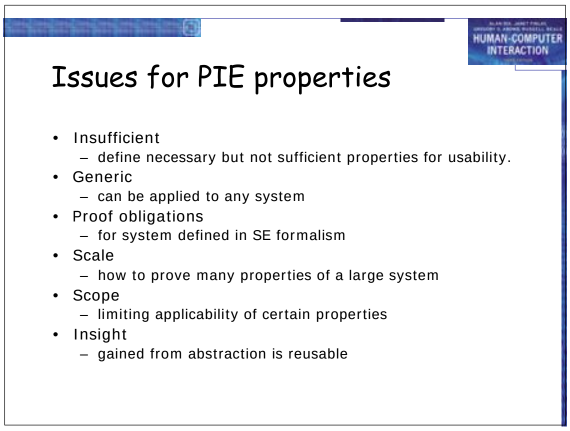




lesson

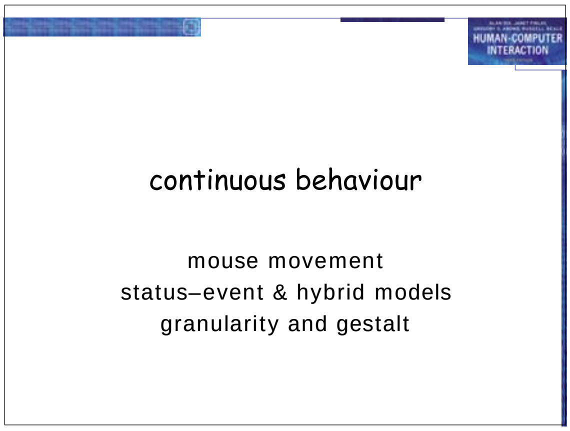
- undo is no ordinary command!

- other meta-commands:
  back/forward in browsers
  history window



Issues for PIE properties

- Insufficient
  - define necessary but not sufficient properties for usability.
- Generic
  - can be applied to any system
- Proof obligations
  - for system defined in SE formalism
- Scale
  - how to prove many properties of a large system
- Scope
  - limiting applicability of certain properties
- Insight
  - gained from abstraction is reusable



continuous behaviour

mouse movement
status–event & hybrid models
granularity and gestalt

dealing with the mouse

- Mouse always has a location
  - not just a sequence of events
  - a *status* value
- update depends on current mouse location
  - doit: E × C × M → E
  - captures *trajectory independent* behaviour
- also display depends on mouse location
  - display: E × M → D
  - e.g.dragging window

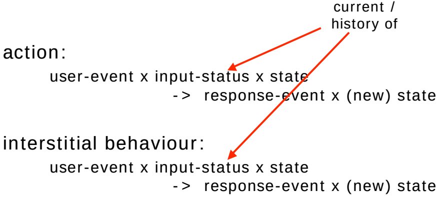
formal aspects of status-event

- events
  - at specific moments of time
    - keystrokes, beeps,
      stroke of midnight in Cinderella
- status
  - values of a period of time
    - current computer display, location of mouse,
      internal state of computer, the weather

interstitial behaviour

- discrete models
  - what happens at events
- status–event analysis
  - also what happens *between* events
- centrality …
  - in GUI – the *feel*
    - dragging, scrolling, etc.
  - in rich media – the main purpose

formalised …



current /
history of

action:

user-event x input-status x state
-> response-event x (new) state

interstitial behaviour:

user-event x input-status x state
-> response-event x (new) state

note:
current input-status => trajectory independent
history of input-status allows freehand drawing etc.

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status-change events

- events can change status
- *some* changes of status are meaningful events
  > when bank balance < $100
  > need to do more work!
- not all changes!
  - every second is a change in time
  - but only some times critical
    > when time = 12:30 – eat lunch
- implementation issues
  - system design – sensors, polling behaviour

more on status-event analysis in chapter 18

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making everything continuous

- physics & engineering
  - everything is continuous
    - time, location, velocity, acceleration, force, mass

$$\frac{dx}{dt} = v \qquad \frac{dv}{dt} = -g \qquad x = vt - {}^1/_2 gt^2$$

- can model everything as pure continuous

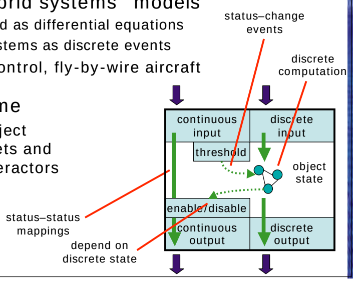
  $state_t = \varphi\ (\ t,\ t_0,\ state_{t0},\ inputs\ during\ [t_0,t)\ )$

  $output_t = \eta\ (\ state_t)$

  - like interstitial behaviour
- but clumsy for events – in practice need both

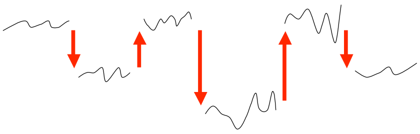
hybrid models

- computing “hybrid systems” models
    - physical world as differential equations
    - computer systems as discrete events
  - – for industrial control, fly-by-wire aircraft
- adopted by some
  - – e.g. TACIT project
    Hybrid Petri Nets and
    continuous interactors



common features

- actions
  - – at events, discrete changes in state
- interstitial behaviour
  - – between events, continuous change



granularity and Gestalt

- granularity issues
  - – do it today
    - » next 24 hours, before 5pm, before midnight?
- two timing
  - – ‘infinitely’ fast times
    - » computer calculation c.f. interaction time
- temporal gestalt
  - – words, gestures
    - » where do they start, the whole matters