Theories and Models for Human-Computer Interaction

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Outline

What is a theory? a model?

Perception, action

Cognition, behavior

Interaction

Software architectures

What is a model?

Model = simplification of reality

- Goal: to be useful!
- Abstraction of reality: omit non-relevant details
- Conflict between precision and generality:
  choose the level of abstraction

Power of a model

- Descriptive: ability to represent (aspects of) a phenomenon
- Predictive: ability to anticipate behavior
- Generative : ability to imagine new solutions to a problem

Notation = description language

- informal, incomplete, inconsistant
- Example : UAN (User Action Notation)

What is a theory?

Theory = (attempt to) explain reality

- Often based on a model
- Validity not only of the predictions of the model,
  but also of the model itself

Falsifiability (Popper)

- A scientific theory must be dispovable through experiments
- A falsified theory can be refined into a “better” theory
  - Example : Newton -> Einstein
    Relativity refines (and includes) classical mechanics

Empirical law = observation of a regularity, without explanation

Perception and action

Pre-attentive perception [Triesman]

Ecological theory of perception [Gibson]

Hick’s law, Fitts’ law

Kinematic chain theory [Guiard]

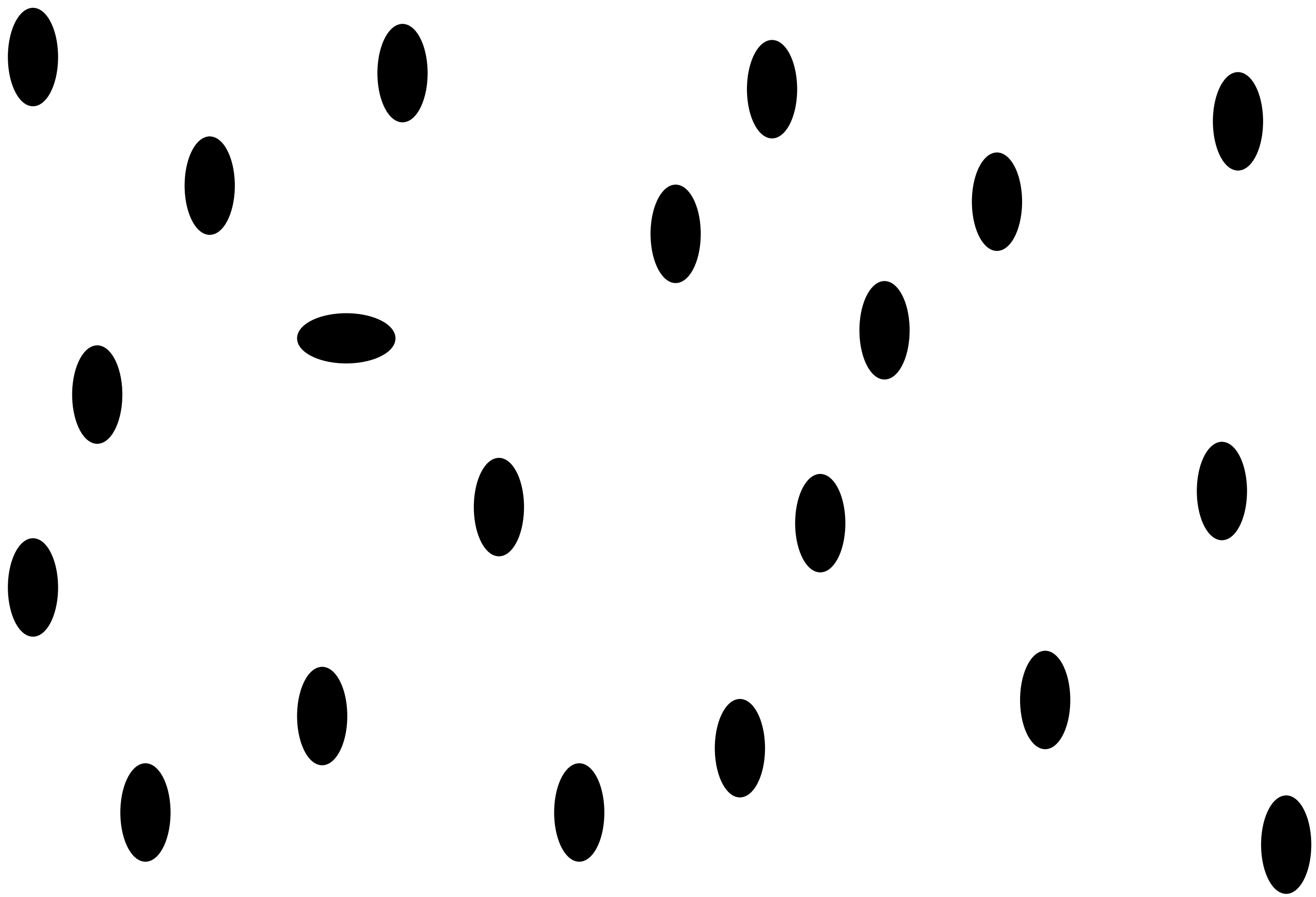
Pre-attentive perception

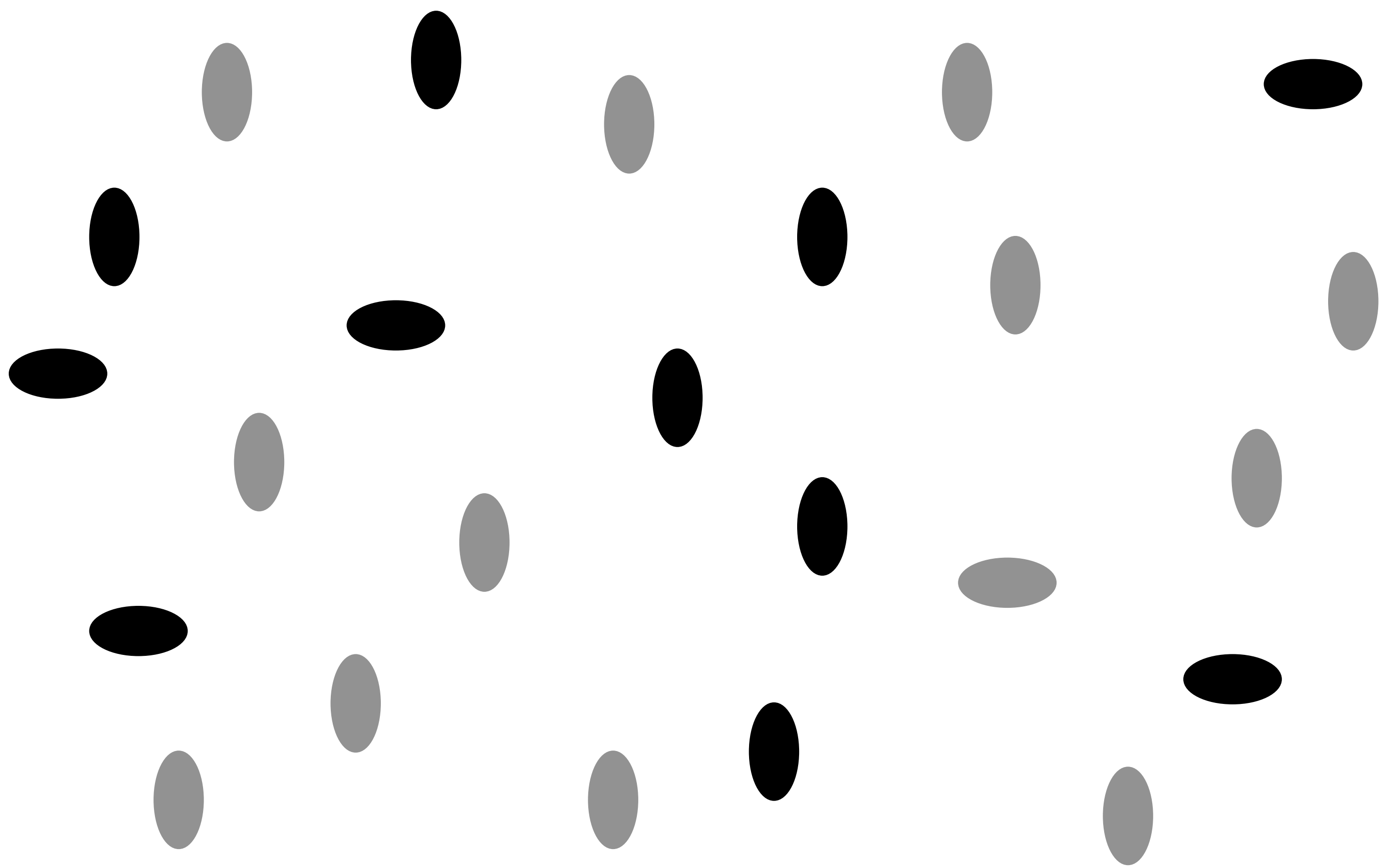
Observation :

- Humans can recognize some visual features very rapidly:
- Line orientation, blobs, length, thickness, size, curvature, cardinality, endings, intersections, inclusion, hue, blinking, movement direction, depth, direction of light source…
- There are interferences when combining several such changes

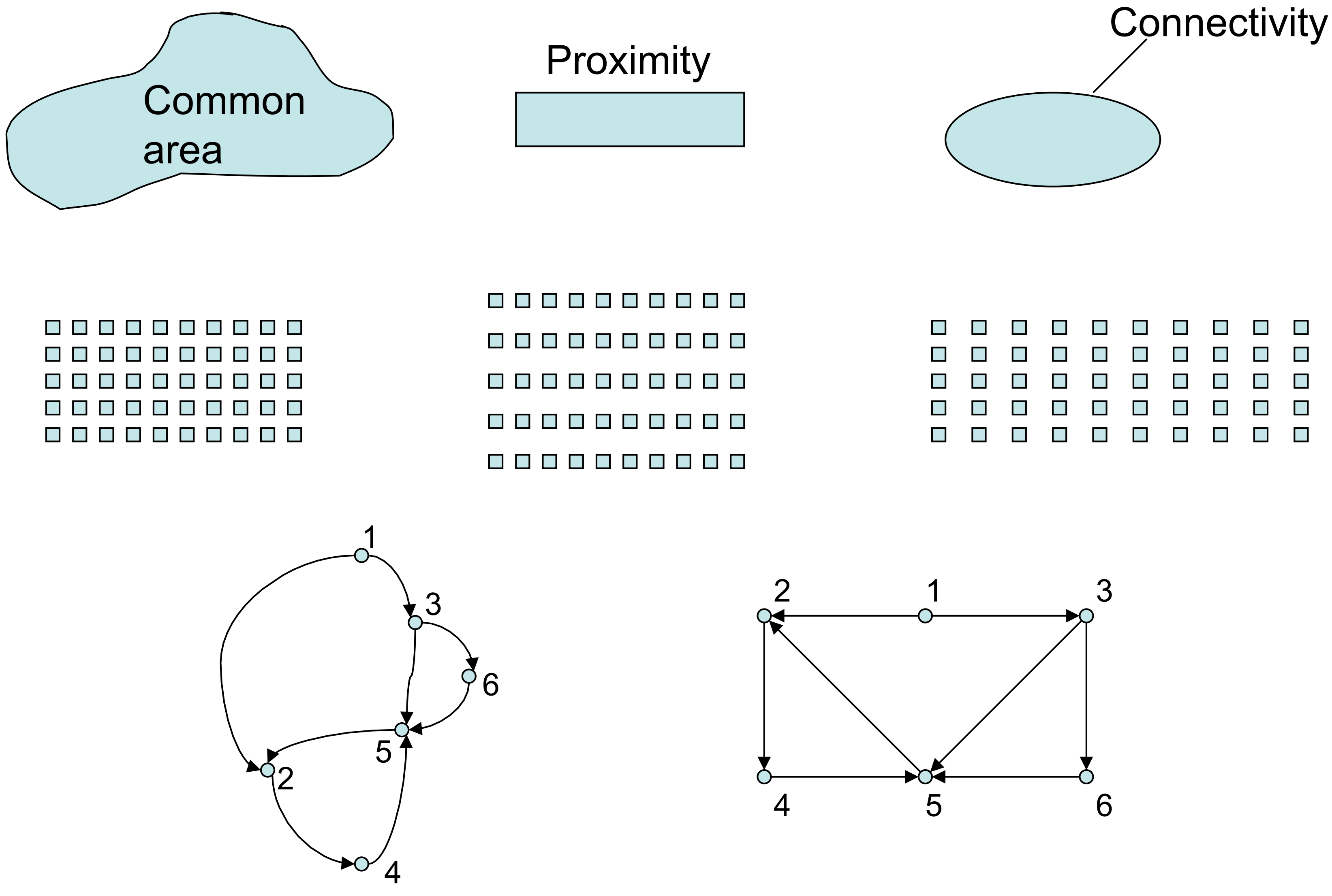
Theory : pre-attentive perception (Triesman, 1985)

- Parallel handling at the level of visual perception
- Information that is not perceived pre-attentively must be handled sequentially
- Links with Gestalt theory





Principles of Gestalt perception



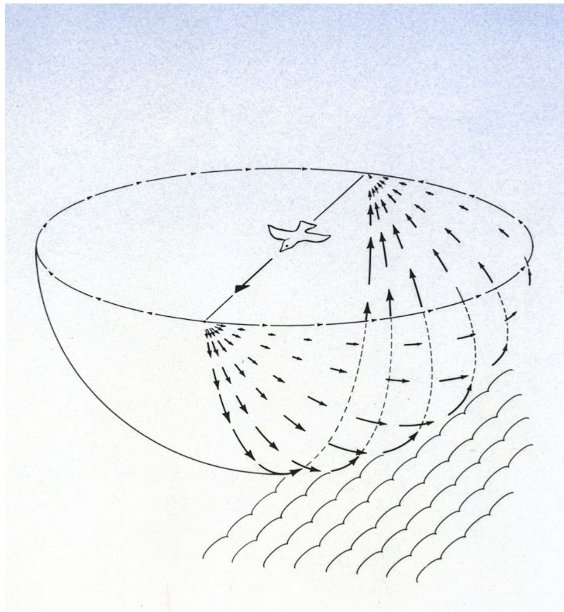
Ecological Theory of Perception

Fundamental hypotheses:

- Co-evolution between organism and its environment
- Behavioral pre-adaptation
- “Elegant” (and parcimonious) perceptual processes

Ecological optics

- Information is in the optical array and the optical flow
- The organism is equiped to extract invariants
  Example : when moving, the only fixed point
  indicates the direction of motion



Relativity of the environment

- Action-perception coupling
- “Affordances”

Hick’s law, Fitts’ law

Empirical laws extracted from controlled observations

Hick’s law: time it takes to select an item in a set

- $RT = a + b \log_2 (n)$
  a & b are constants, n is the number of items

Fitts’ law: time it takes to acquire a target

- $MT = a + b \log_2 (1 + D/W)$
  a & b are constants
  D = distance to target (amplitude)
  W = pointing tolerance (width of the target)
- Information-based theory of percpetion

This laws are valid only in precise experimental settings

Kinematic chain theory

Laterality of motor control

- Classical psychology:
  "the left hand is a bad right hand"
- Observations of bimanual control:
  the two hands have different *roles*

Kinematic chain:

- Non-dominant hand: distal control
  - Acts first
  - Establishes the frame of reference (context) for the dominant hand
  - Movements do not need to be precise
- Dominant hand: proximal control
  - Acts after the non-dominant hand,
    within the frame of reference it establishes
  - Precise movements

Falsification :

- Some tasks are more efficient when the hands have symetric roles

Cognition and behavior

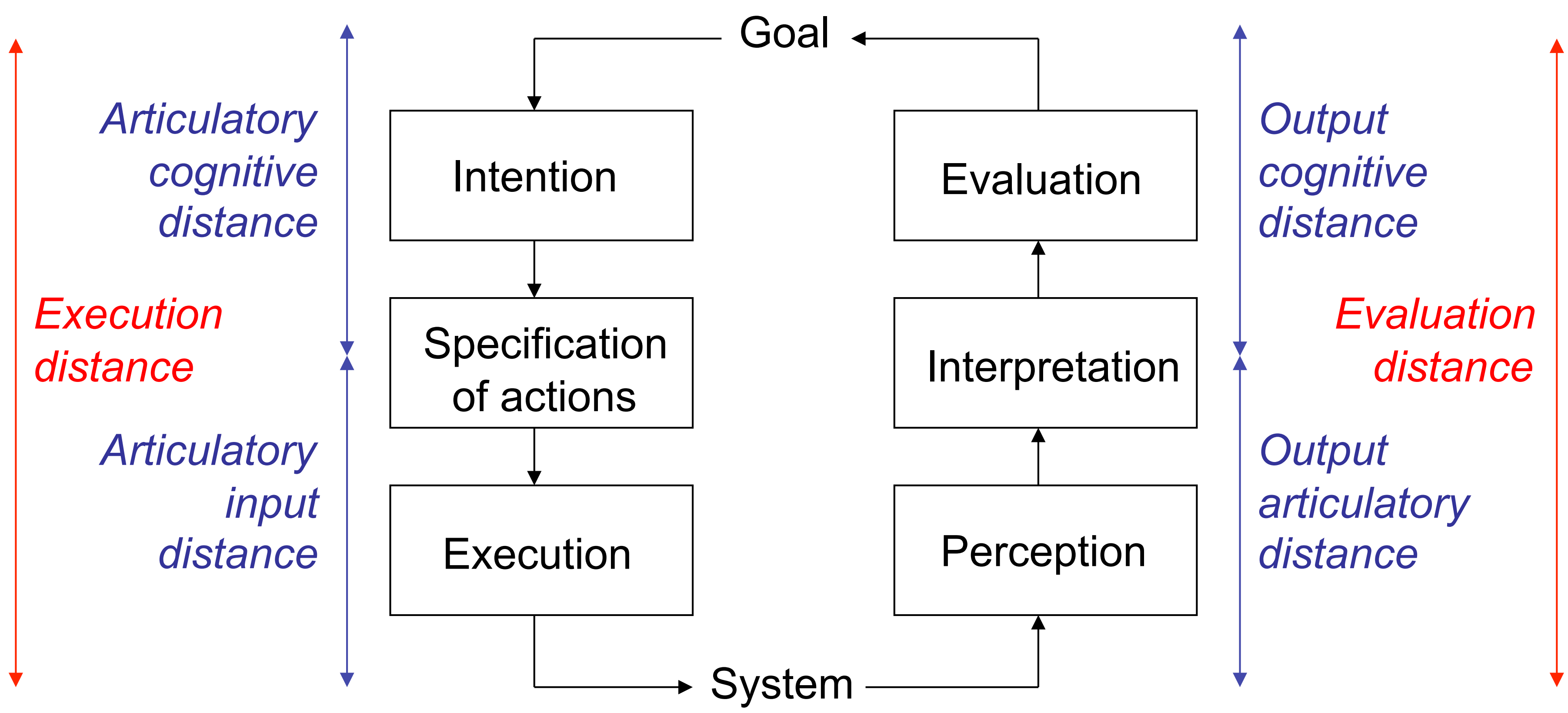
Action theory [Norman]

Situated action [Suchman]

Activity theory [Vigotsky, Bødker]

Cognitive dimensions [Green]

Action theory



Situated action

Classical cognitivist approach:

- Cartesian model where all actions are planned and human action is explained by cognitive processes
- Examples : action theory, task analysis, mental models

Ethnomethodological approach:

- Detailed analysis of work practices in order to determine the causal chains implied by the observed actions

Situated action:

- Human action takes place in a complex context that creates constraints and dependencies and affects the actions being undertaken
- If there is a plan, at best it is used as a guide
- Action adjusts to the context at hand and at the same time modifies it

Activity theory

Vigotsky: analysis of human activity

- Subject-object relationship is mediated by tools (technical instruments) or signs (psychological instruments)

Leontiev : emphasis on the role of the community

- Rules and rituals, division of labor

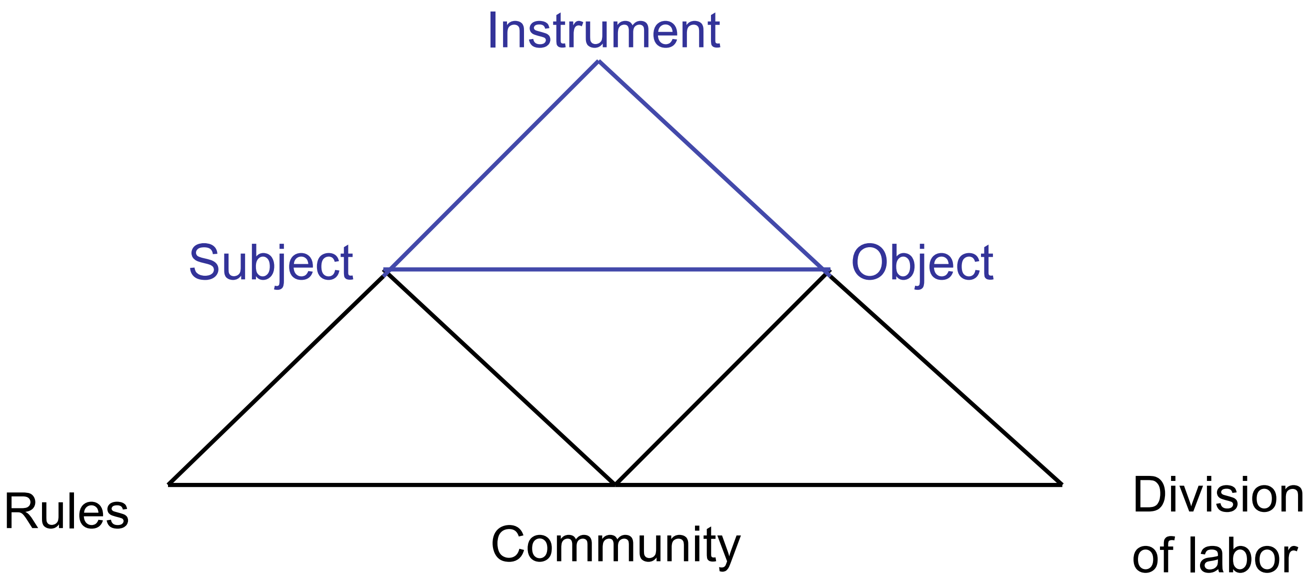
3 levels of activity:

- Activity: responds to a need (materialistic or intellectual) – Why
- Actions: executed consciously to reach an explicit goal set by the subject – What
- Operations: executed unconsciously or semi-consciouly to execute actions – How

Activity theory

Levels of activity:

- Action -> operation: automation / internalisation
- Operation -> action: conceptualisation (e.g., in case of failure)
- Activity -> operation: according to the context



Cognitive dimensions

Notation :

- Tool to help interaction designers
- Evaluating a system according to certain criteria
- Scientific foundation: importance of representation to solve a problem

6 types of activity:

- Incrementation : add data
- Transcription : copy from another source
- Modification : change content, adapt to a new problem
- Exploration : trial and error to find a solution
- Search: look for an object that may not exist
- Comprehension : discover an unknown aspect of the system

Cognitive dimensions

Dimensions : aspects of the informational structure that can be analyzed according to the activity being studied.

Some examples :

- Viscosity: resistance to change
- Visibility: ability to see components easily
- Premature commitment: constraints on the order of actions
- Hidden dependencies: important but hidden links between entities
- Role expressiveness: the role of an entitiy is easy to infer
- Abstraction : types and availability of abstraction mechanisms
- Consistency : similar semantics are expressed with similar syntax
- etc.

Interaction

Morphological analysis of input devices [Card et al.]

UAN [Hartson]

State machines [Newman]

GOMS [Card-Moran-Newell]

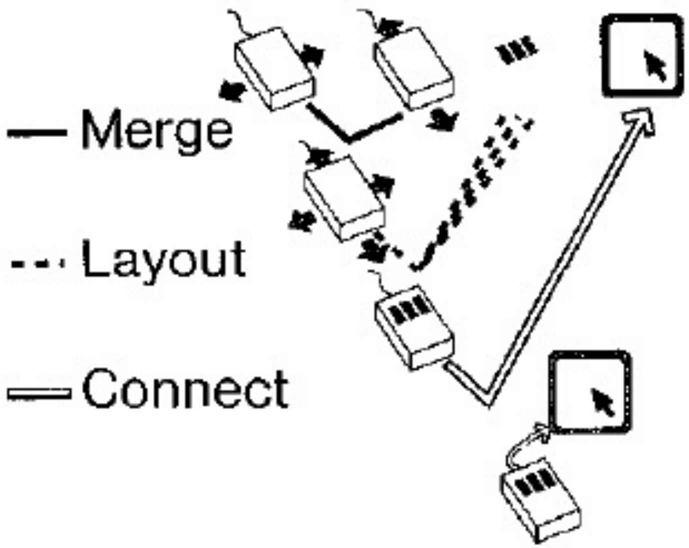
Instrumental interaction [Beaudouin-Lafon]

Morphological analysis of input devices

Description of the properties of an input device:

Transducer of physical properties into logical properties

- M = Manipulation operation
  - position/force, absolute/relative => P, F, dP, dF
  - linear/circular => X, Y, Z / rX, rY, rZ
- In = Input domain
- S = Current state of the device
- R = Resolution function: In -> Out
- Out = Output domain
- W = Other properties of interest

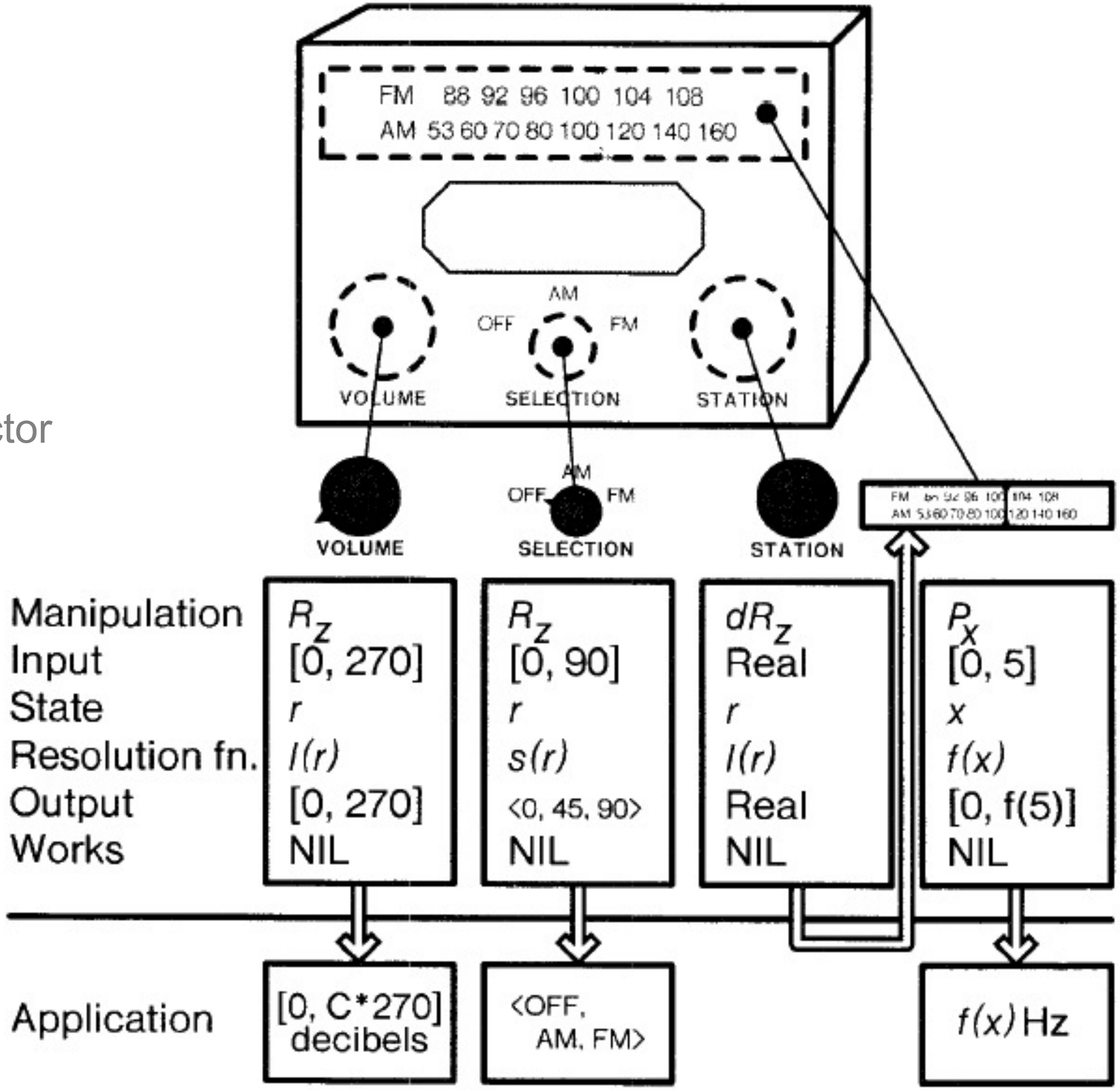


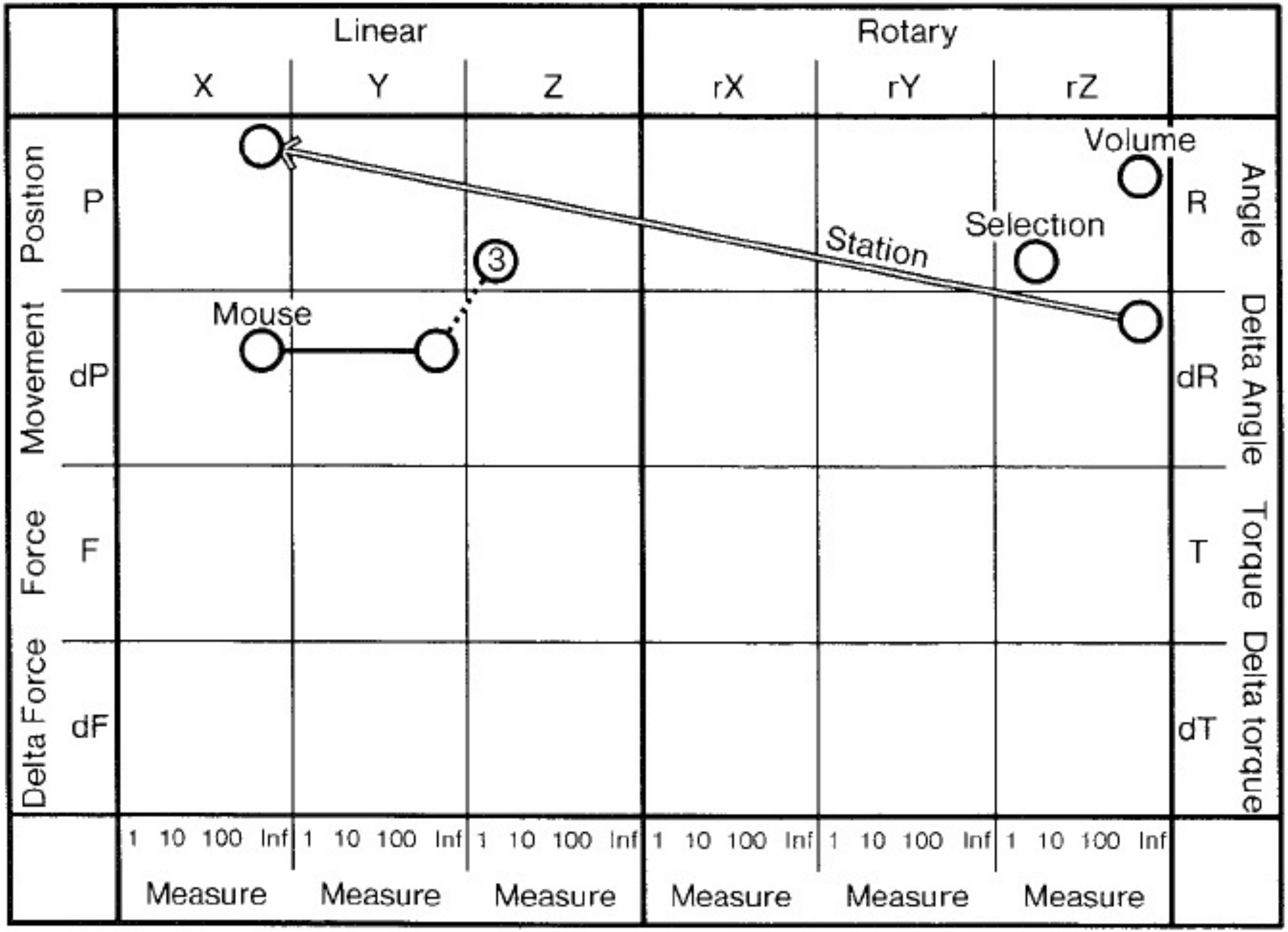
Composition of input devices:

- Merge
- Layout
- Connect

Example

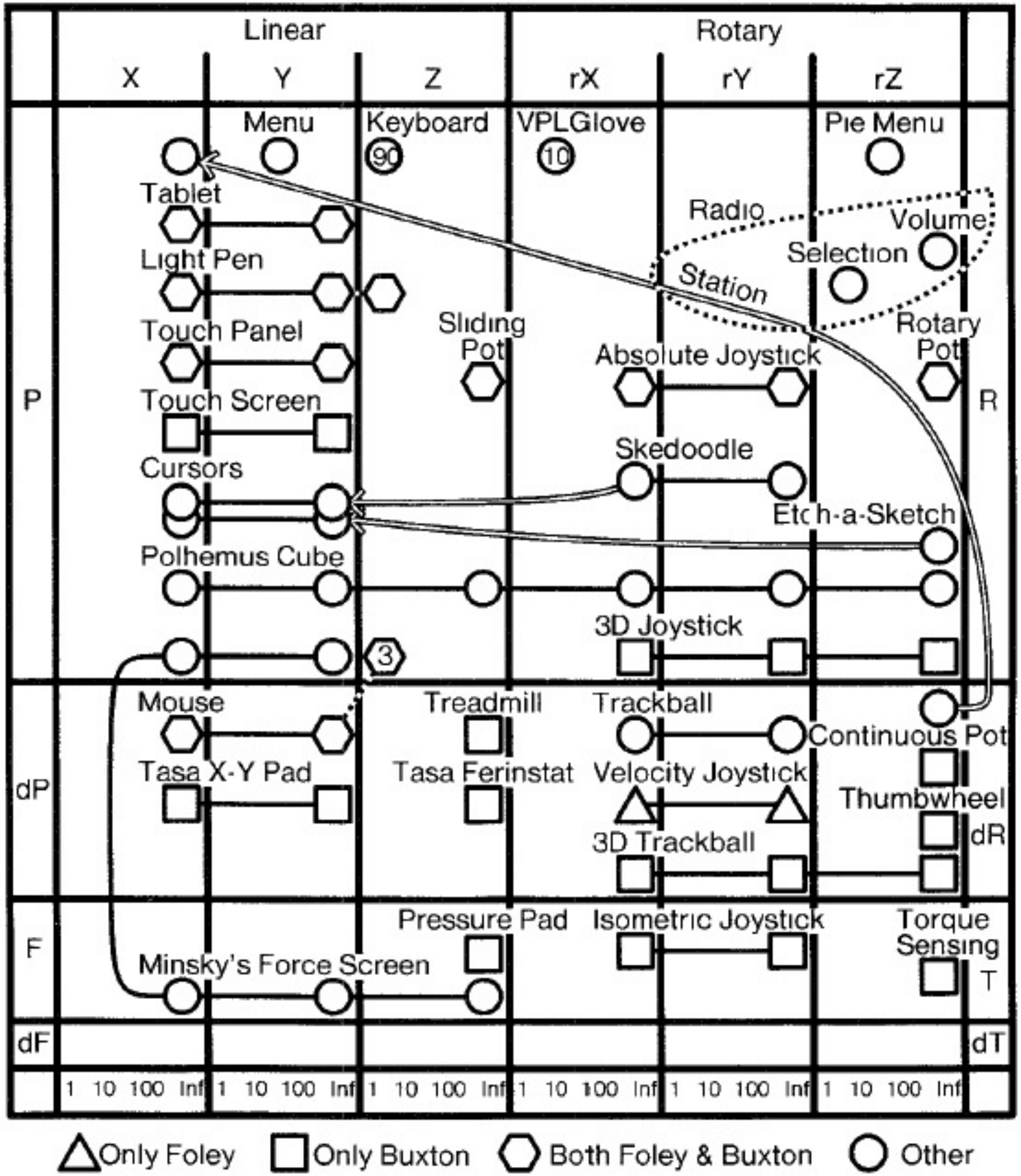
Radio :
- Volume dial
- AM/FM selector
- Frequency selector




Linear
Rotary
X
Y
Z
rX
rY
rZ
Position
P
Movement
dP
Force
F
Delta Force
dF
Angle
R
Delta Angle
dR
Torque
T
Delta torque
dT
Mouse
3
Station
Selection
Volume
1 10 100 Inf
Measure

Taxonomy

Comparison of input devices, including those studied by Foley and by Buxton



UAN : User Action Notation

Description of user actions and system responses

Example : selecting an icon

Action	Feedback
~[icon] Mv^	icon!

More accurate version:

~[icon] Mv	icon-! : icon! , all icon'! : icon'-!
M^	

Moving an icon:

~[file_icon] Mv	file_icon-! : file_icon! , all icon'! : icon'-!
~[x,y]* ~[x',y']	outline(file_icon) > ~
M^	@x',y' display(file_icon)

UAN

Action	Feedback	Interface state	Computation
~[file_icon] Mv	file_icon-! : file_icon! , all icon’! : icon’-!	selected = file	
~[x,y]* ~[x’,y’]	outline(file_icon) > ~		
M^	@x’,y’ display(file_icon)		pos(file_icon) = x’,y’

Informal notation

- Usable with a standard keyboard
- Easy to remember
- Separates symbols from their meaning
- Can be extended if needed:
  - New symbols
  - New columns (e.g., cognitive load)

State machines

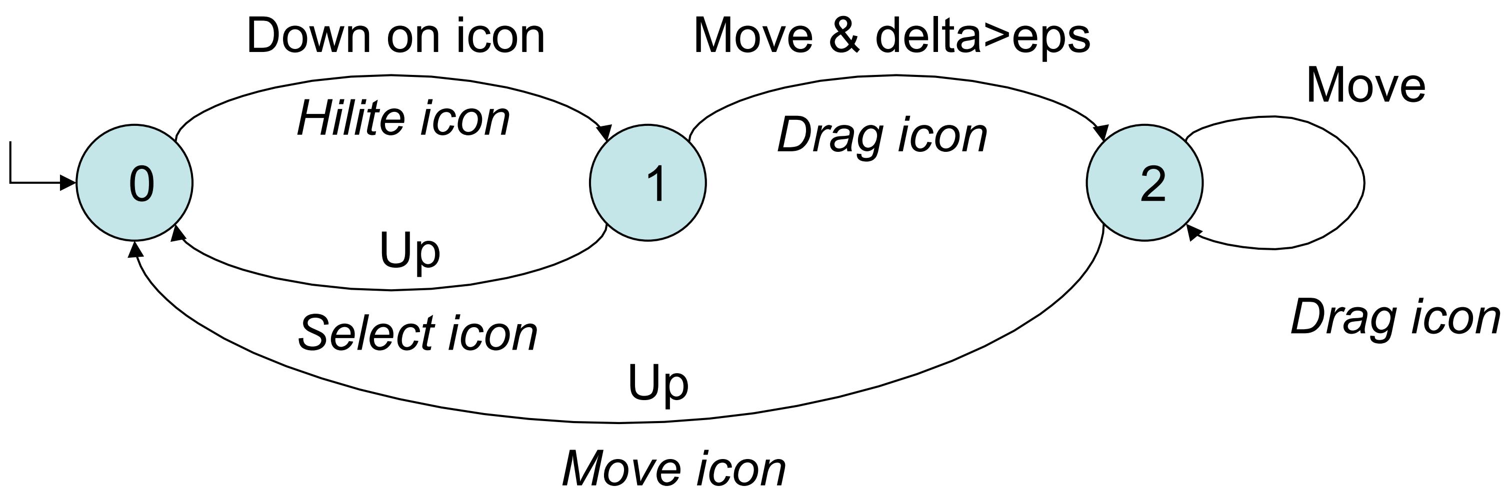
Formal description of the behavior of the interface

Extend finite state automata or transition networks:

- ATN (augmented transition networks)
- RTN (recursive transition networks)
- Statecharts (Harel)
- Petri nets

Proof and validation of properties is possible

Direct link to implementation



The GOMS family of models

GOMS = Goals, Operators, Methods, Selection rules

- **G**oals: what the user wants to do
- **O**perators: actions supported by the software application
- **M**ethods: learned sequences of subgoals and operators to reach a goal
- **S**election rules: users' personal rules to choose one of several methods

GOMS is both:

- A method to describe user tasks
- A set of descriptive (and sometimes predictive) models, used at several levels of abstraction

GOMS models are task analysis techniques based on models of information processing

Example : move a sentence in a text

Initial goal: edit text

Sub-goal: select text to move

Operators: a. move the mouse

b. clic mouse button

c. enter key on keyboard

Methods:

- For editing: 1. Delete sentence and type again
  2. Cut-paste using keyboard shortcuts
  3. Cut-paste using menu items
- For selection : 4. Click and drag text
  5. Double-click first word, shift-click last word

Selection rules:

- For editing: method 1 if the text is short, method 2 if the user knows the shortcuts, methode 3 otherwise.
- For selection: method 4 if the text to be moved is not a set of complete words, method 5 otherwise.

KLM : Keystroke-Level Model

Six operators in the original version:

- K – hit key or button (0.08s - 1.20s, mean 0.40s)
- P – pointing a target with the mouse (1.10s)
- H – Homing = moving hand between mouse and keyboard (1.00s)
- D – Drawing a line segment (0.9n + 0.16l, n segs de long. l)
- M – Mental activity to prepare for next action (1.35s)

"Magical" rules for placing operator M

Example : Method 5 then 3

- Selection: M PK PK
- Copy command: M PK PK
- Select destination: M PK
- Paste command: M PK PK   total = 14.9s

CMN-GOMS : Card-Moran-Newell GOMS

Evolution of the Keystroke-level model

- Some additional operators
- Computer support
  - Automatic evaluation of predicted times
  - Automatic evaluation of selection rules

Predictive model (as is KLM)

- Helps compare various methods for a single task
- Example : shows that the selection rule for moving the cursor with the mouse vs. the keyboard tends to choose the optimal method.

Problem: tendency to overestimate execution times

- Operators have a fixed duration
- Learning is not taken into account

CPM-GOMS : Critical-Path Method

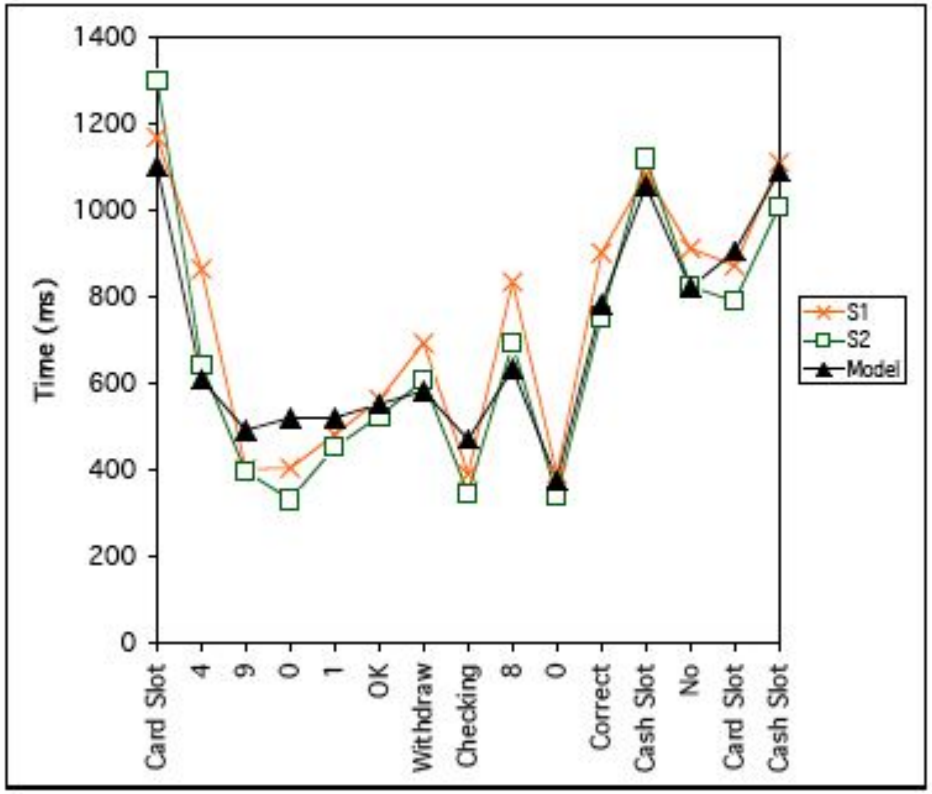
Based on the Model Human Processor (MHP)

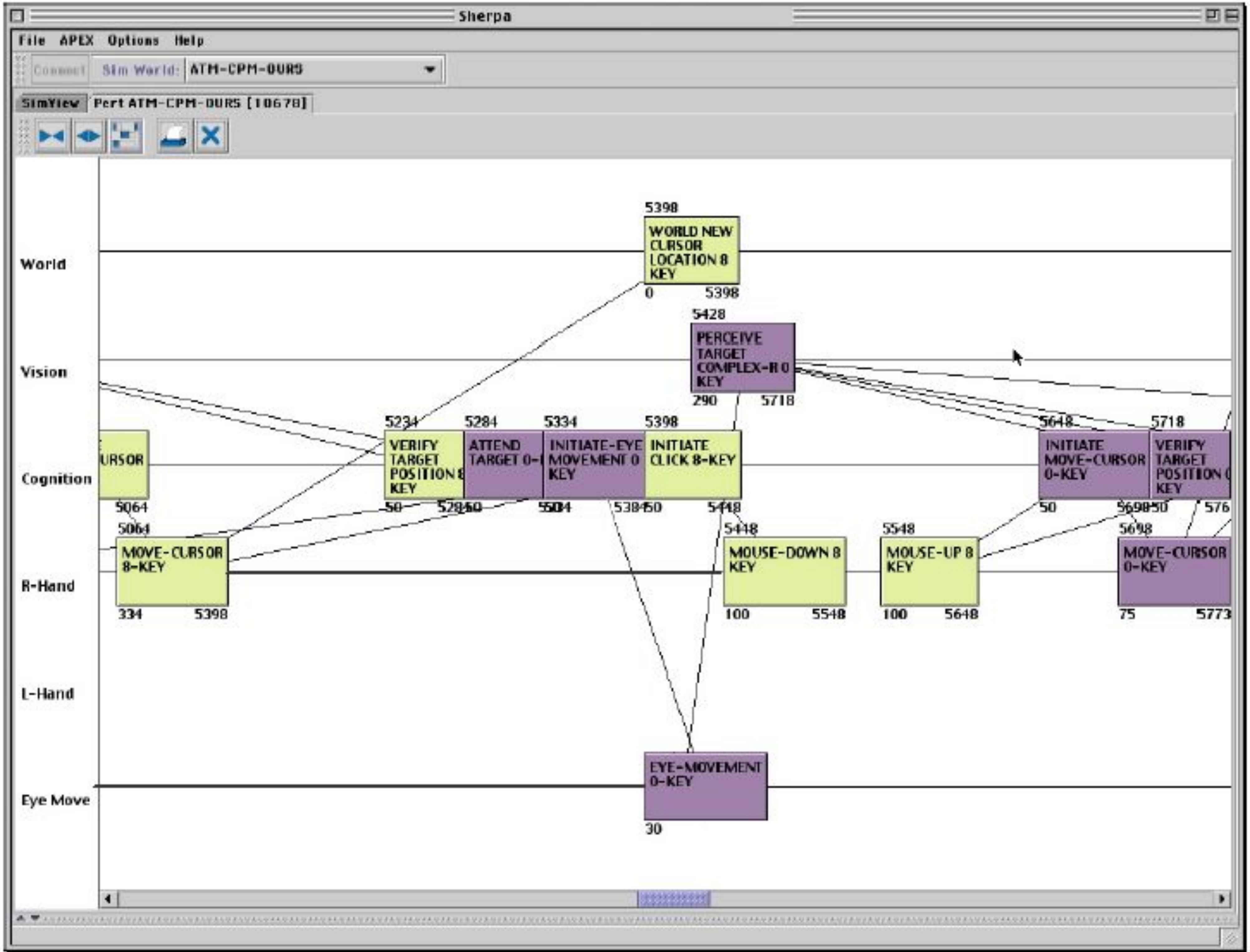
- Parallel processing of perceptual, cognitive and motor activities
- PERT diagram created from the CMN-GOMS description of the task using templates of MHP operators for elementary tasks

Predictive power:

- Performance prediction is more accurate than KLM
- Qualitative analysis using the critical path in the PERT diagram

APEX : tool that automates the creation of diagrams

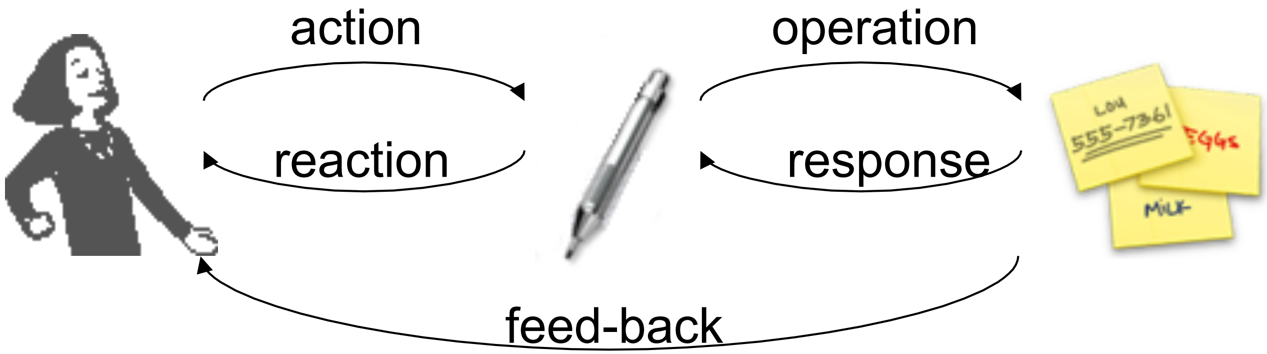



Sherpa
File APEX Options Help
Connect Sim World: ATM-CPM-OURS
SimView Pert ATM-CPM-OURS [10678]
World
Vision
Cognition
R-Hand
L-Hand
Eye Move
WORLD NEW CURSOR LOCATION 8 KEY
PERCEIVE TARGET COMPLEX-R 0 KEY
VERIFY TARGET POSITION 8 KEY
ATTEND TARGET 0-
INITIATE-EYE MOVEMENT 0 KEY
INITIATE CLICK 8-KEY
INITIATE MOVE-CURSOR 0-KEY
VERIFY TARGET POSITION KEY
MOVE-CURSOR 8-KEY
MOUSE-DOWN 8 KEY
MOUSE-UP 8 KEY
MOVE-CURSOR 0-KEY
EYE-MOVEMENT 0-KEY

Instrumental Interaction

Interaction model

- Describes an interface in terms of *domain objects* and *instruments*



Descriptive aspect

- Covers a large set of existing techniques (GUI, tangible, AR, ...)

Predictive aspect

- Properties for comparing instruments
  - Degree of indirection, degree of integration, degree of compatibility

Generative aspect

- Design principles: reification, polymorphism, reuse

Software architecture models

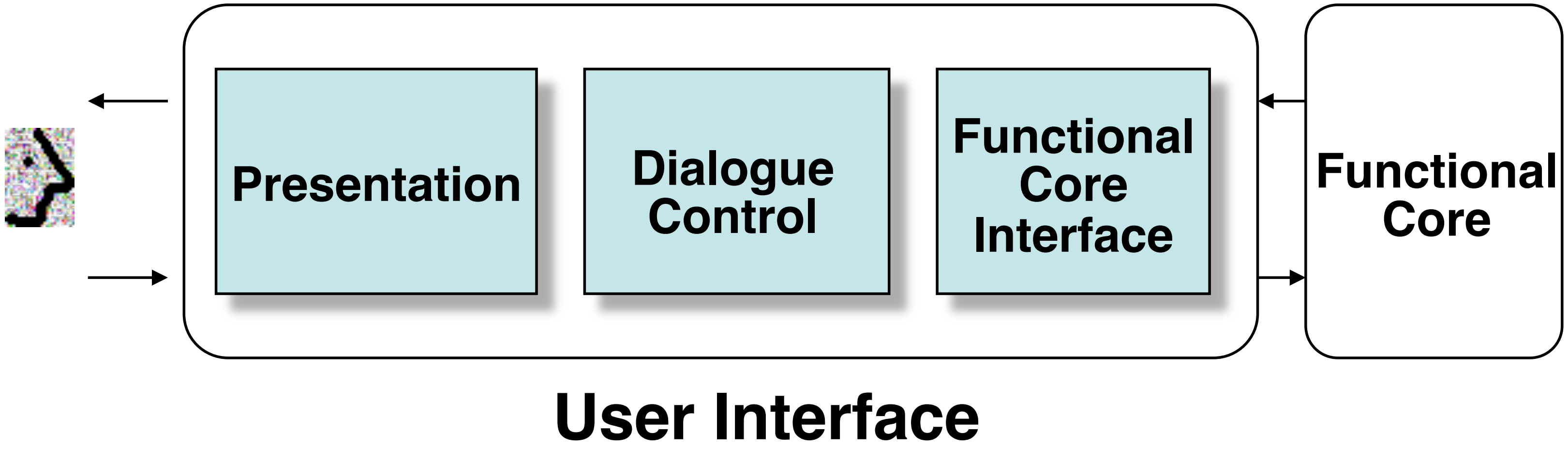
Seeheim

MVC - Model-View-Controller

Arch

PAC - Presentation-Abstraction-Contrôle [Coutaz]

Seeheim



Presentation

- Manages input and display at a low level

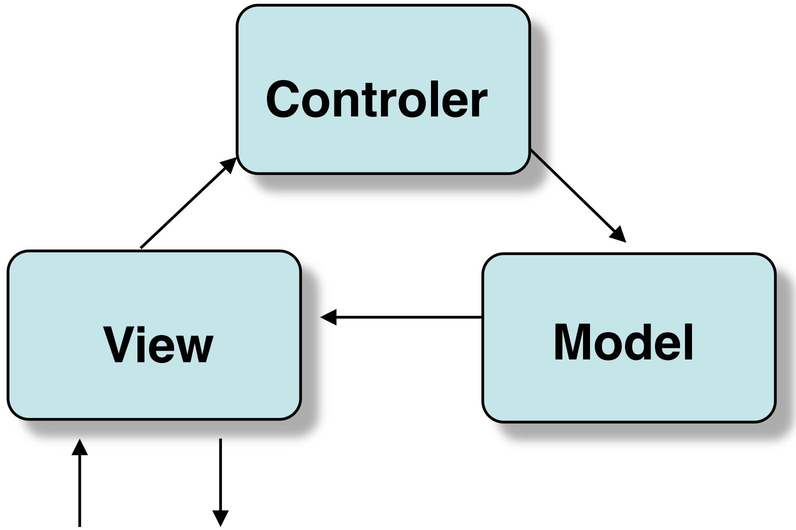
Dialogue control

- Validates input and transforms it into commands
- Transforms responses from the Functional Core into graphical entities

Functional core interface

- Adapts the functional core to the needs of the interface

MVC - Model-View-Controler

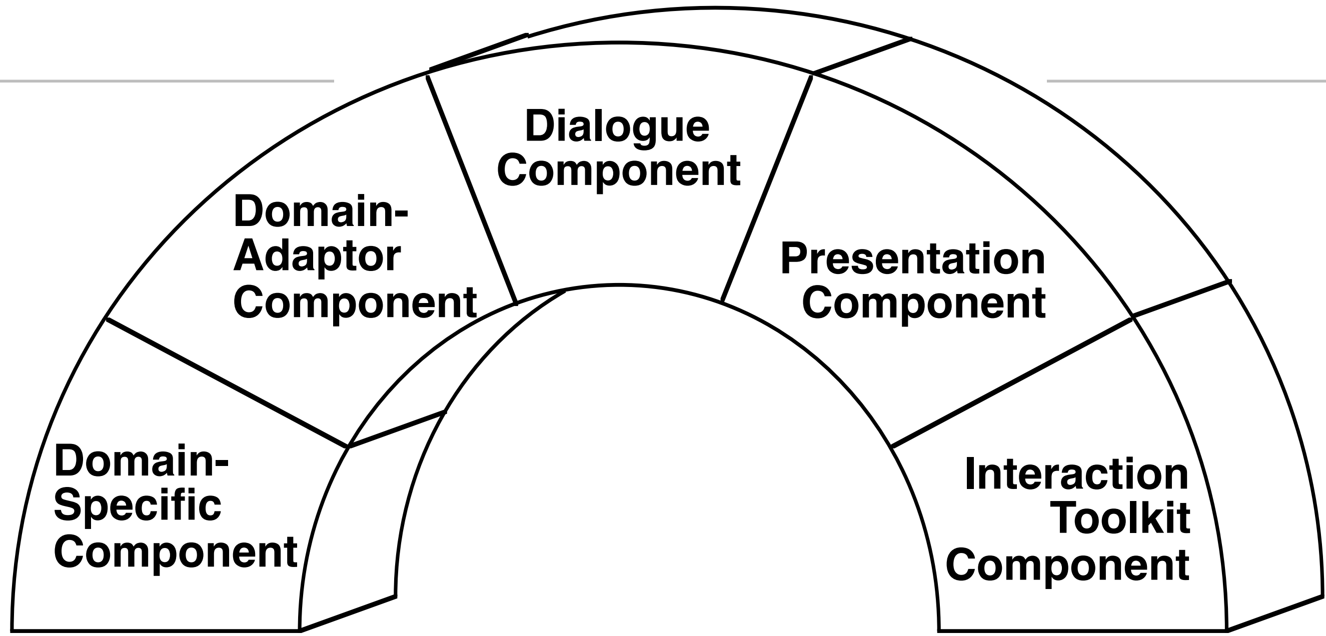


Interface = hierarchical composition of MVC triplets

- Model: abstract representation of the interactive object
- View: graphical representation and input management
- Controler: updates the model when the view is edited

Implemented originally in the Smalltalk system

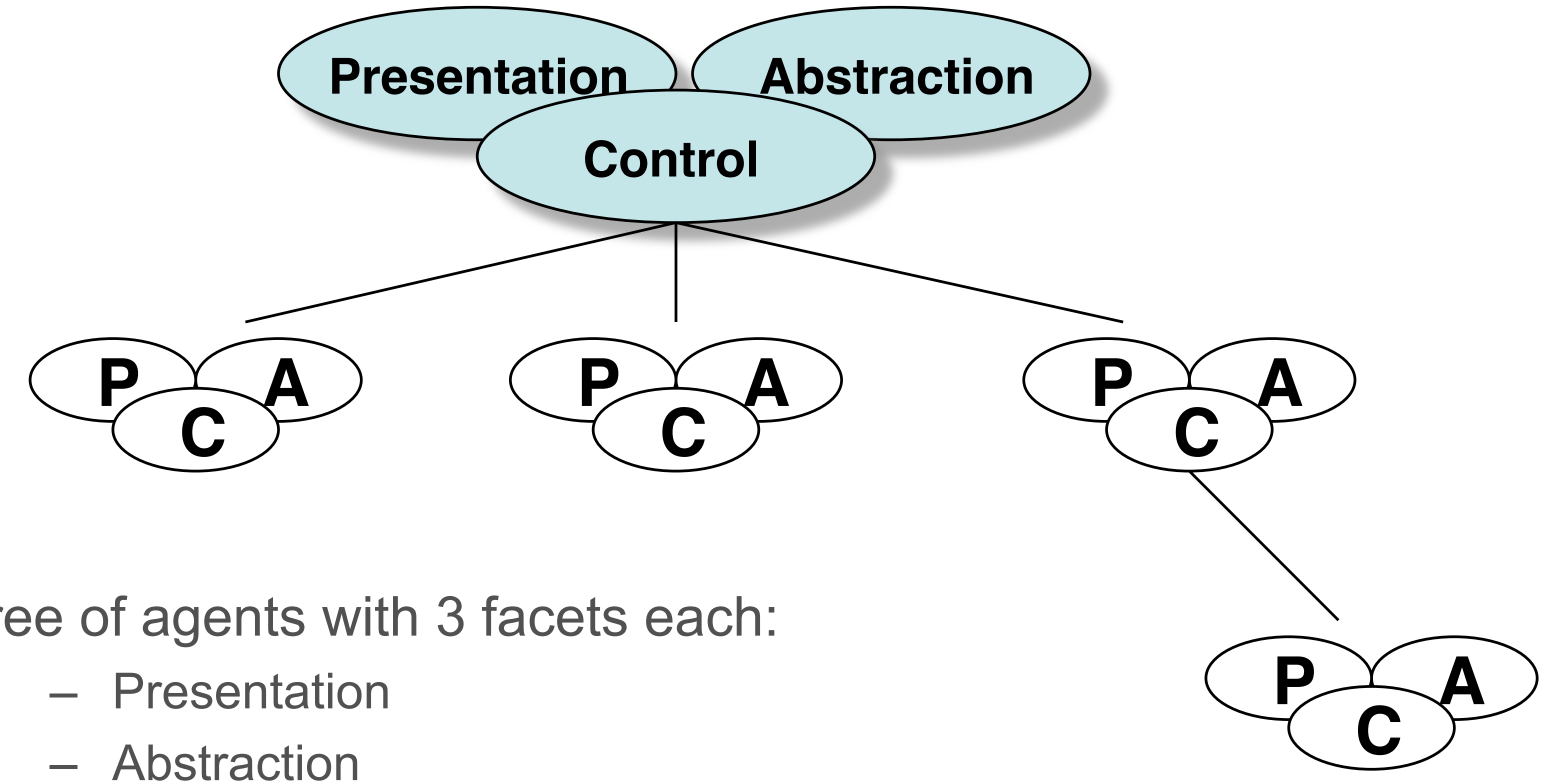
Arch



Modern version of Seeheim

- Acknowledges the existence of user interface toolkits
- Adaptators
  - On the presentation side
  - On the functional core side
- Components can be of different sizes, or even non-existant

PAC - Presentation-Abstraction-Control



Tree of agents with 3 facets each:

- Presentation
- Abstraction
- Control

Heuristics for the structure of the tree (e.g., multiple views)

Abstract model: no software platform (unlike Smalltalk for MVC)

Numerous evolutions: PAC-Amodeus, PAC*, CoPAC, etc.

Conclusion

Models and theories in human-computer interaction

- Borrowed from Psychology
  - Action/Perception, Cognition
- Borrowed from Sociology
  - Ethnomethodology
- Borrowed from Computer Science
  - Automata
- Specific to HCI
  - GOMS, Instrumental Interaction

Models and theories in HCI are more often desciptive than predictive, and they are rarely generative

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