Ergonomic design

Underlying concepts
Design space
Rules of thumb, heuristics

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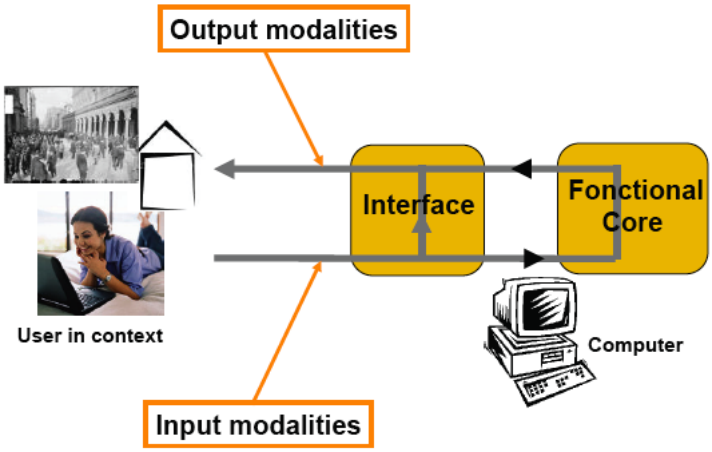
Underlying concepts



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Underlying concepts
The Pipeline Model

- A data flow model:
  - user's intention -> user's physical actions
  - system's acquisition function:
    - user's physical actions -> input conceptual units
  - system's action:
    - input conceptual units -> an effect (a system state change)
  - system's rendering function:
    - effect -> output conceptual units
    - output conceptual units -> system's physical actions
  - user's perception, interpretation, evaluation
    - systems' physical actions -> new mental model

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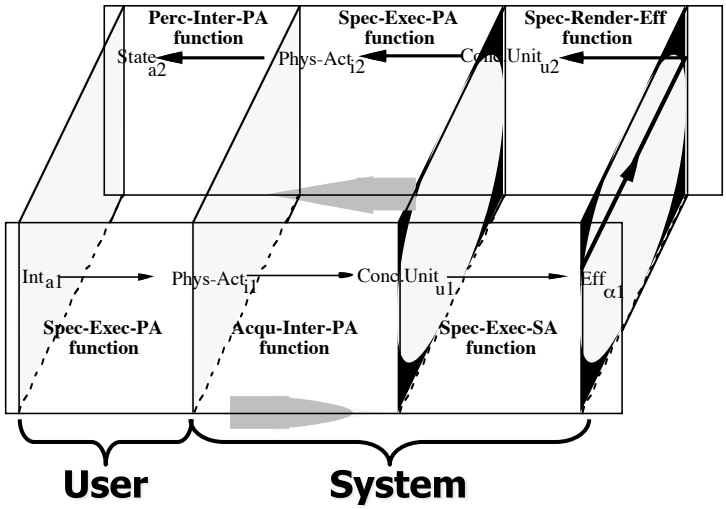
The Pipeline Model



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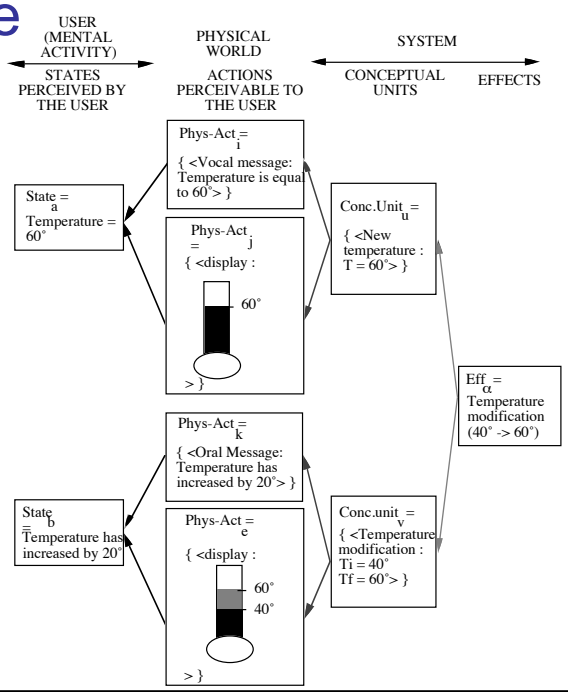
The Pipeline Model



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The Pipeline Model

- 2 concepts as point of contact between the user and the system:
  - interaction language
  - physical device
- Interaction language: set of well formed expressions used by the system or the user to exchange information
- Inter. language & phys. device = 2 facettes of an expression
  - interaction language = the structure (Hemjslev's form)
  - physical device = the observable (Hemjslev's substance)

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The Pipeline Model: the utility

- A bridge between user and system perspectives using simple concepts: L&D
  - interaction language
  - physical device
- Derivation of properties that may be of interest for user modelers: the CARE props.
  - complementarity, assignment, redundancy, equivalence
- Classification of interactionally rich systems in terms of L&D: the UOM method
  - multiplicity of L&D
  - in a given state, options for the system/the user between multiple L&D
  - in a given state, usage by the system/the user of L&D
- Implication on software architectures
  - which components are L-dependent, D-dependent, etc.

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Underlying concepts Definition of a modality

- Built-in cognitive capability of the system for interpretation and rendering
- Input modality
  Interpretation function: sequence of transformations from input “raw information”
- Output modality
  Rendering function: sequence of transformations to output “raw information”

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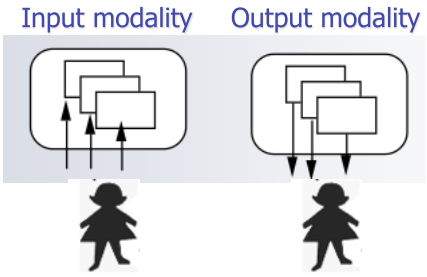
Definition of a modality

- Modality = (device, interaction language)
  - A set of sensors (input devices) or effectors (output devices)
  - A processing facility based on a language



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Definition of a modality

- Modality = (device, interaction language)
  - A set of sensors (input devices) or effectors (output devices)

    Perception/Action
  - A processing facility based on a language

    Cognition

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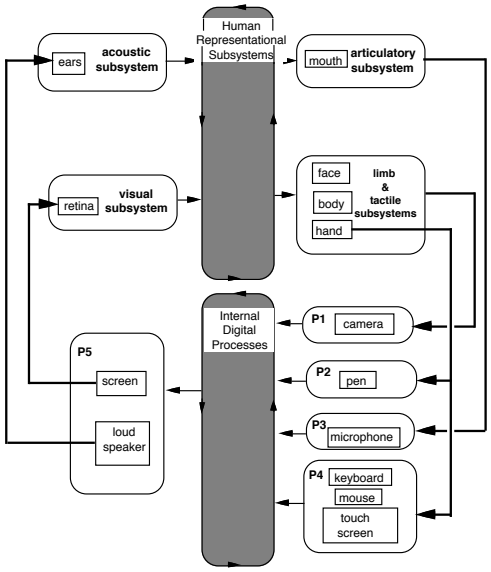
Definition of a modality

- Theory ICS
  - APU Cambridge



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Definition of a modality

- Modality = (device, interaction language)
- Multimodality
  - Multi device Mono Language
  - Multi device Multi Language
  - **Mono device Multi Language**
  - e.g. table and graph displayed on screen as two different modalities
    - M1 = (screen, table) and M2 = (screen, graph)

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Definition of a modality

- Modality = (device, interaction language)
- Recent interaction paradigms such as perceptual User UI tangible UI and embodied UI open **a vast world of possibilities**
  - M1 = (microphone, natural language)
  - M2 = (keyboard, command language)
  - M3 = (mouse, direct manipulation)
  - M4 = (PDA, 3D gesture) ***embodied UI***
  - M5 = (HMD, 3D graphics) ***AR***
  - M6 = (bottle-sensor, 3D gesture) ***tangible UI***
  - M7 = (GPS, localization) ***perceptual UI***
  - *M8 = (Tongue display, 2D shape)*

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Definition of a modality

- Input Modality = <d, l>

Speech = <  , natural language>

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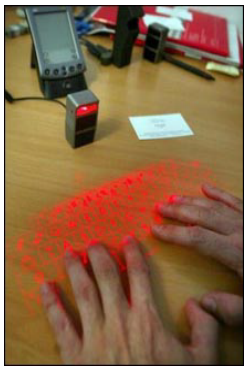
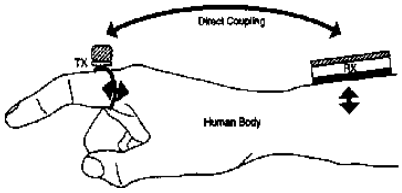
Definition of a modality

- Input M = <device, text>





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Definition of a modality

Input M =
<camera, Gesture>

Input M =
<microphone, NL>

Input M = <PDA, Gesture>
Embodied modality

Input M =
<stylus, direct manipulation>

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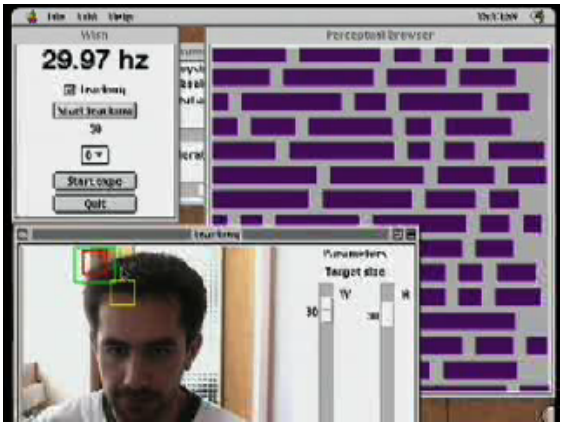
Definition of a modality

- Input M = <camera-head, gesture>



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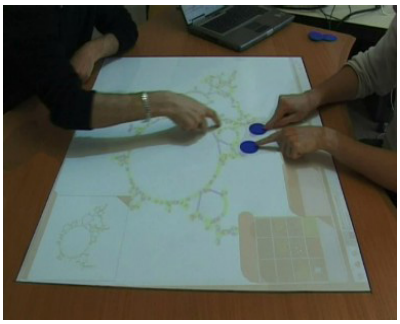
Definition of a modality

- Input M =
  <camera-token, direct manipulation>



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Definition of a modality

- Input M = <bottle-sensor, gesture>

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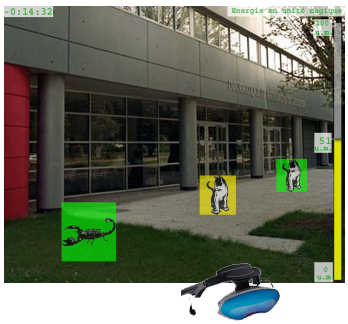
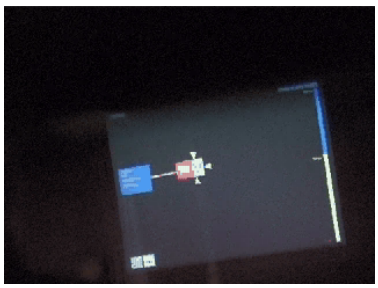
Definition of a modality

- Input Modalities (*sensing modalities*)
- M1 = <GPS, localization>
- M2= <magnetometer, orientation>





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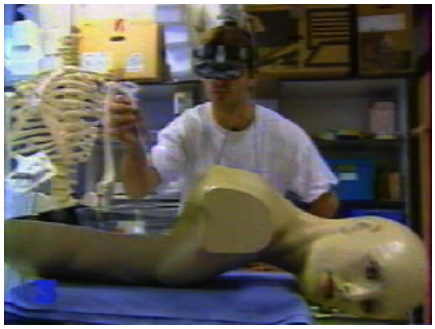
Definition of a modality

- OUTPUT Modality = <d, I>

  M = <HMD, 3D graphics>



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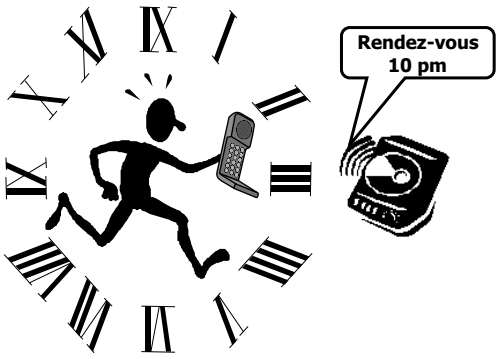
Definition of a modality

- Output M = <loudspeakers, NL>
- 3D sound:



Soundbeam Neckset

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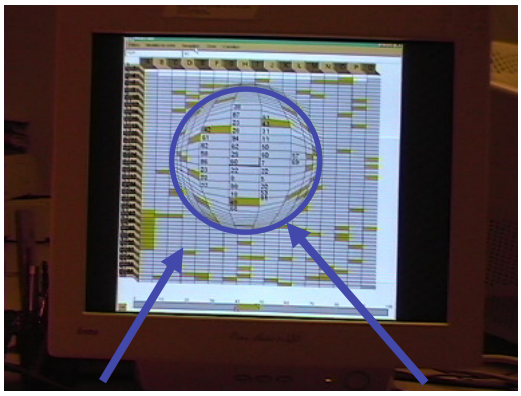
Definition of a modality

- Complementarity of output modalities



Output M1 = <screen, table>

Output M2 = <screen, deformed table>

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Underlying concepts

- Modality = (device, interaction language)
  - Input modality
    - Interpretation function: sequence of transformations from input "raw information"
  - Output modality
    - Rendering function: sequence of transformations to output "raw information"
- Four intertwined ingredients (for both):
  - 1. Levels of abstraction
  - 2. Context
  - 3. Fusion and fission
  - 4. Granularity of concurrency

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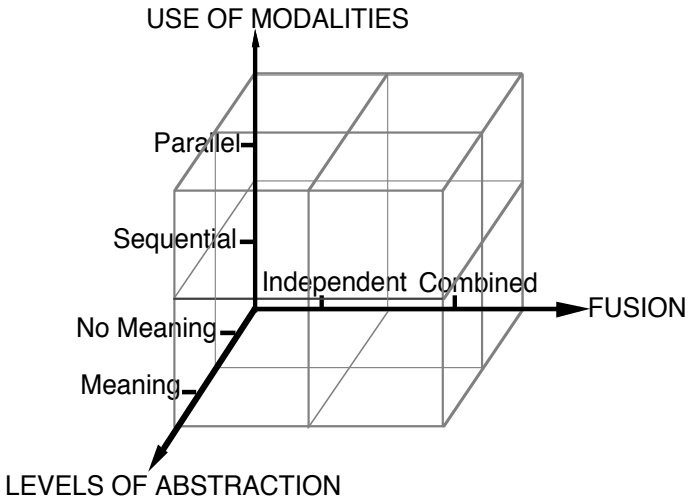
Underlying concepts



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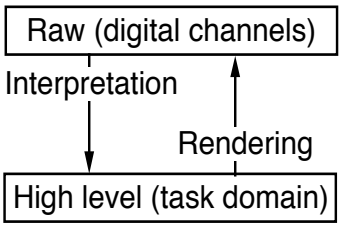
Dimension 1: Levels of Abstraction

Expresses the variety of representations supported by the system:



Interpretation function: Ability to abstract

Rendering function: Ability to materialize

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Dimension 1: Levels of Abstraction

Example: Speech input and output

Interpretation function **Ability to abstract to**	Rendering function **Ability to materialize from**
Digital signal	Symbolic representation of meaning
Word or a pattern of words	Pre-stored text message (text to speech)
Meaningful sentence	Pre-recorded vocal message

We consider two values only:
MEANING / NO MEANING

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Dimension 1: Levels of Abstraction

- The capacity of abstraction may vary with the context
- Example : VI text editor
  - command mode: text is processed -> high level
  - input mode: text is recorded only -> raw
- Context of commands
  high level interpretation
- Context of task-domain data
  low level interpretation

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Dimension 2: Use of Modalities

- Supported use of modalities
- Sequential:
  Use of the modalities one after another
- Parallel:
  Use of multiple modalities simultaneously
  - Multiple devices used simultaneously

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Dimension 3: Fusion

- Fusion: Combination of chunks
- It occurs at multiple levels of abstraction
- Lowest level: chunks from distinct modalities
- Higher levels: chunks from dictinct contexts

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Dimension 3: Fusion

- **Lowest level: chunks from distinct modalities**
- Independent: (Absence of fusion)
  Independent interpretation/rendering process for each modality
- Combined: (Presence of fusion)
  Fusion of data expressed using different modalities
  - "Put that there" paradigm
  - => Combination of different types of data

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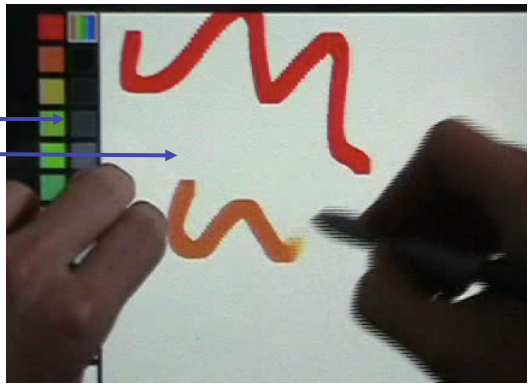
Dimension 3: Fusion

- **Higher levels: chunks from dictinct contexts**
- Single input channel, multiple context
- For example:
  - Fusion of events
    - Palette
    - Drawing area



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Multimodal versus multimedia

A multimodal system:

Value "Meaning" along the axis "Levels of Abstraction"

=> Four types of multimodal systems

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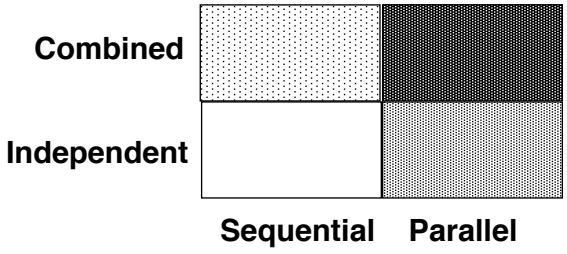
Multimodal system: four types

- **Exclusive: (Sequential, Independent)**
- **Alternate: (Sequential, Combined)**
- **Concurrent: (Parallel, Independent)**
- **Synergic: (Parallel, Combined)**



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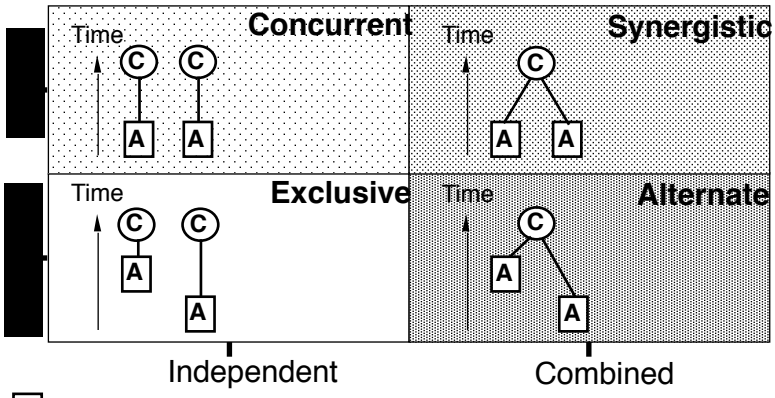
Multimodal system: four types

A multimodal system:
Value "Meaning" along the axis "Levels of Abstraction"



A User's actions
C Command, smallest fusion of user's actions that changes the system state

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How to classify a system

To classify a given system:

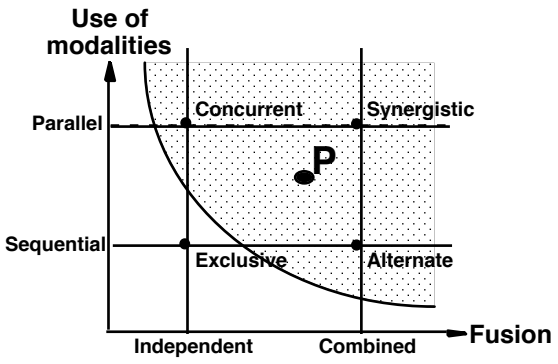
1. A set of its features fi:

fi = (pi,wi) **wi: the weight**
pi: the position

2. The position P of the system is defined by:

$$P = \frac{1}{\Sigma_w} \times \sum_i pi \times wi$$

$$\Sigma_w = \sum_i wi$$



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Ergonomic design

Underlying concepts

Design space

Rules of thumb, heuristics

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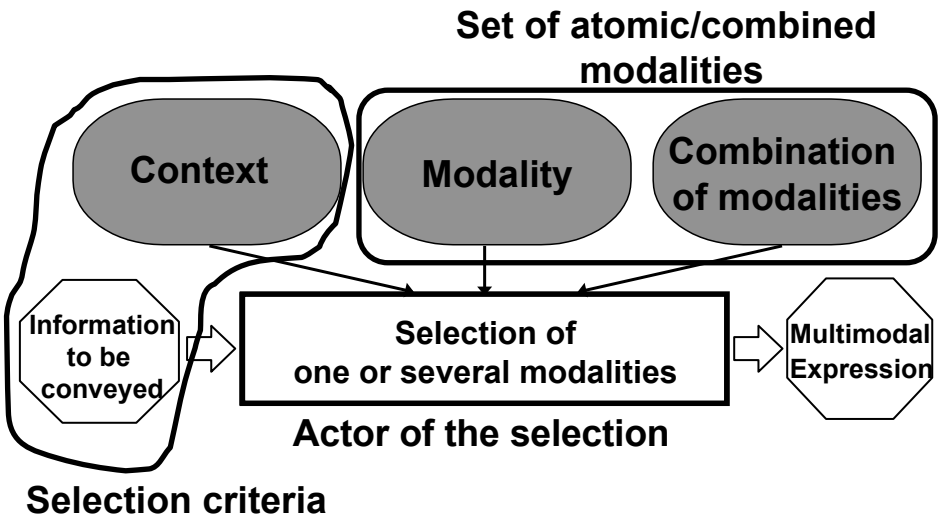
Multimodality: Design space



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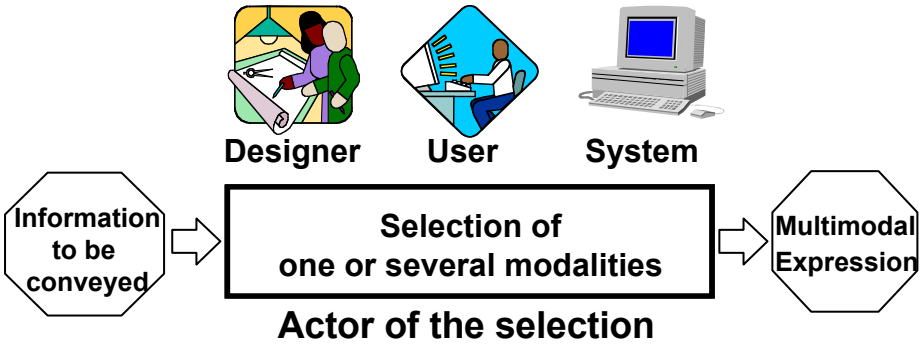
Multimodality
Actor of the selection

- Who is performing the selection



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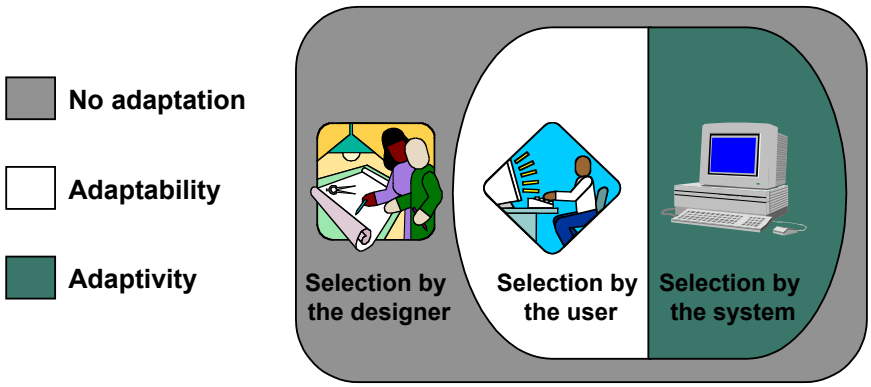
Multimodality
Actor of the selection



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Multimodality Adaptability

Gestural modality

Speech

Embodied modality

Direct manipulation

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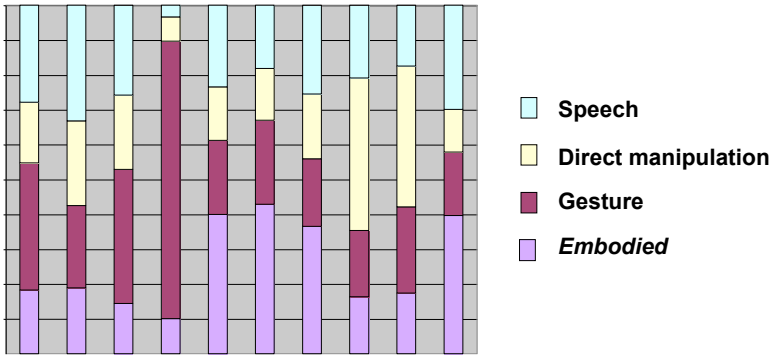
Multimodality Adaptability

- Usage of the modalities
- All sessions / All subjects



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Multimodality
Adaptativity

- Selection of the modalities by the system
- Context-aware systems

Ring

Vibration

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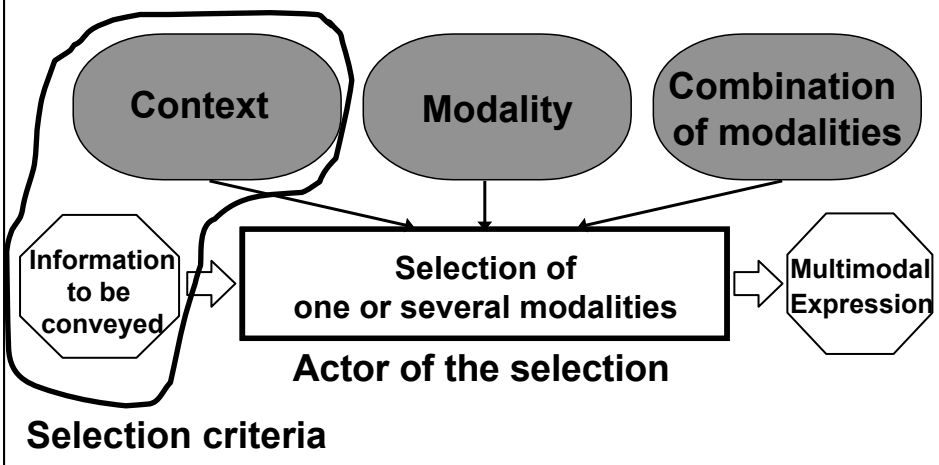
Multimodality: Design space



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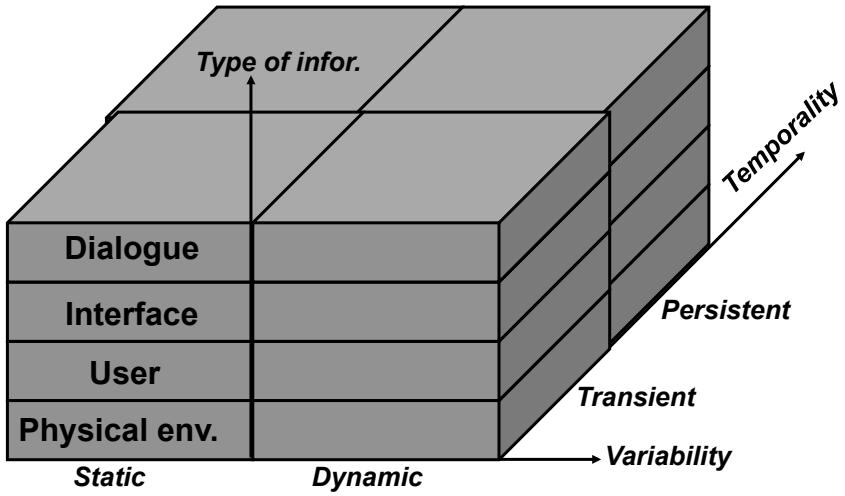
Multimodality
Selection criteria: Context



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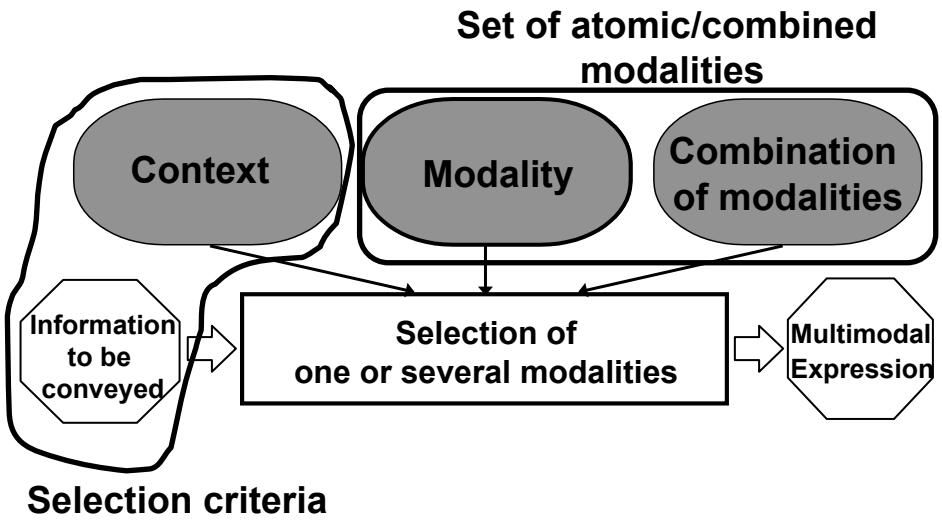
Multimodality: Design space



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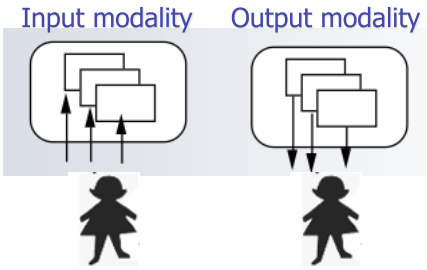
Multimodality
Characterisation of a modality

- Definition of a modality
- Modality = (device, interaction language)
  - A set of sensors (input devices) or effectors (output devices)
  - A processing facility based on a language



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Multimodality
Characterisation of a modality

- **ACTIVE** MODALITIES
  - For inputs, active modalities are used by the user to issue a command to the computer such as a pedal to move a laparoscope in a CAS system.
- **PASSIVE - IMPLICIT** MODALITIES
  - Passive modalities are used to capture relevant information for enhancing the realization of the task, information that is not explicitly expressed by the user to the computer (PUI). For example tracking position.

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Multimodality
Characterisation of a modality

- Human sense
- Passive/Active
- Private / Public
- Spatial
  - Location
- Temporal
  - Transient/Persistent

Modality

- Dimension: *1D 2D ...*
- *O. Bernsen 93*
  - Linguistic
  - Analogue
  - Arbitrary

Physical level

Modality = <device,

Logical level

interaction language >

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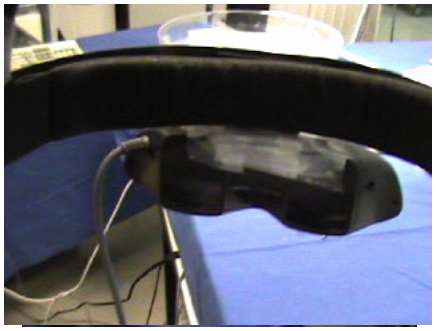
Multimodality
Characterisation of a modality



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Multimodality
Characterisation of a modality

- **Physical level**
  - **Human sense: Sight**
  - **Spatial:**
    Location = operating field
  - **Temporal: Persistent**
- **Logical level**
  - **3D**
  - **Analogue**
  - **Non arbitrary**

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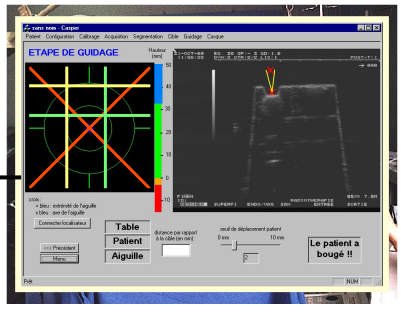
Multimodality
Characterisation of a modality

- **Physical level**
  - **Human sense: Sight**
  - **Spatial: Location = screen**
  - **Temporal: Persistent**
- **Logical level**
  - **2D**
  - **Non Analogue**
  - **Arbitrary**



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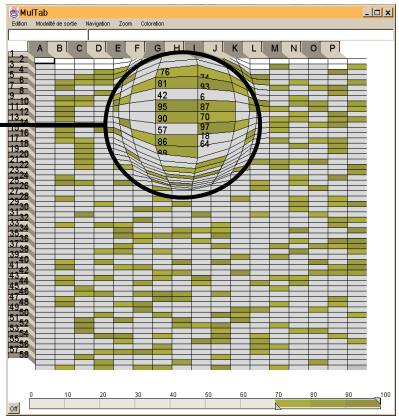
Multimodality
Characterisation of a modality

- Characterisation of a modality

- **Physical level**
  - **Human sense: Sight**
  - **Spatial: Location = screen**
  - **Temporal: Persistent**
- **Logical level**
  - **3D**
  - **Analogue**
  - **Non arbitrary**



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Multimodality
Characterisation of a modality

- Phycons as input modalities

- **Physical level**
  - **Human manipulation**
  - **Spatial: Location = desk**
  - **Temporal: Persistent**
- **Logical level**
  - **3D gesture**
  - **Analogue**
  - **Non Arbitrary**

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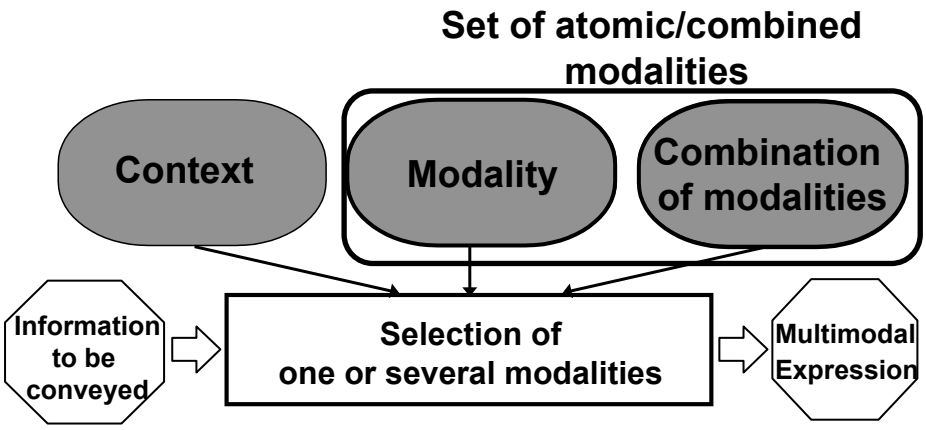
Multimodality: Design space



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Multimodality
Combination of modalities

- Several studies
  - UOM 94 / TYCOON 95 / CARE 95
- CARE properties
  - Relationships between Devices, Interaction languages and Tasks
    - C : Complementarity
    - A : Assignment
    - R : Redundancy
    - E : Equivalence

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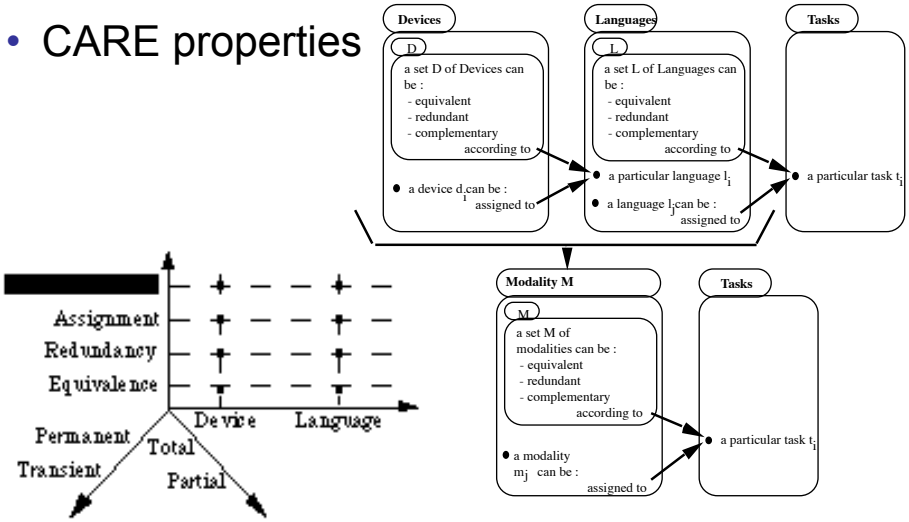
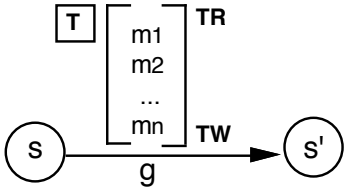
Multimodality
Combination of modalities

- CARE properties



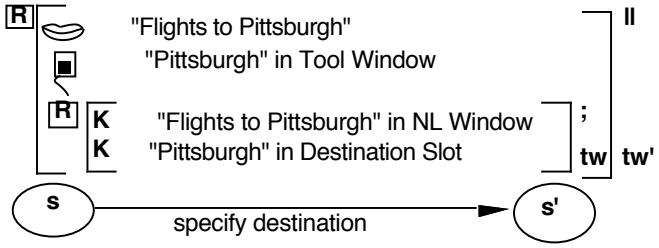
Multimodality
Combination of modalities

- CARE properties
- The formal expression of the CARE properties relies on the notions of state, goal, modality, and temporal relationships.
- A modality is an interaction method that an agent can use to reach a goal.



Multimodality
Combination of modalities

- Redundancy : Modalities of a set M are used redundantly to reach state s' from state s, if they have the same expressive power (they are equivalent) and if all of them are used within the same temporal window, tw.



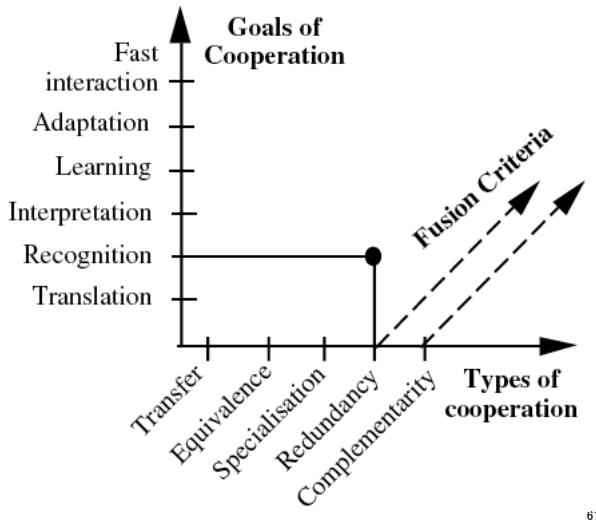
Multimodality
Combination of modalities

- Redundancy : Modalities of a set M are used redundantly to reach state s' from state s, if they have the same expressive power (they are equivalent) and if all of them are used within the same temporal window, tw.
  - Redundancy (s, M, s', tw) ⇔ Equivalence (s, M, s') ∧ (Sequential (M, tw) ∨ Parallel (M, tw))
  - Parallel (M, tw) ⇔ (Card (M) > 1) ∧ (Duration(tw) ≠ ∞) ∧ (∃t∈tw · ∀m∈M · Active (m, t))
  - Sequential (M, tw) ⇔ (Card (M) >1) ∧ (Duration (tw)≠∞) ∧ (∀t∈tw · (∀m, m'∈M · Active(m, t) ⇒ ¬Active(m', t)) ∧ (∀m∈M · ∃t∈tw · Active(m, t))

Multimodality
Combination of modalities

- TYCOON

Each type of cooperation may be involved in several goals. For instance, redundancy between messages uttered and typed on the keyboard by the user may improve recognition. Only redundancy and complementarity need ***fusion*** *which may use combination of several criteria (dotted arrows).*



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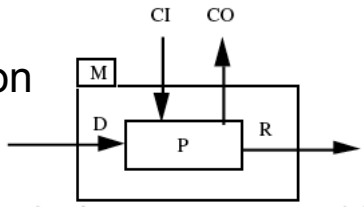
Multimodality
Combination of modalities

- TYCOON
- Logical formalism to describe the combination
- M = { P, D, R, C }
  - A process P
    - controlled by a set of parameters C (CI Input parameters CO Ouptut parameters)
    - analyzing a set of data D
    - to give a set of results R



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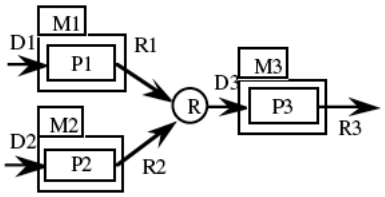
Multimodality
Combination of modalities

- TYCOON M = { P, D, R, C }
- Redundancy

for each possible result r3 of modality M3, the results r1 obtained by modality M1 and r2 obtained by modality M2 have been merged by an intermediate process R and have the same value for an attribute att. The criterion used by R is a parameter of the redundancy definition and may be a combination of temporal coincidence, spatial coincidence...



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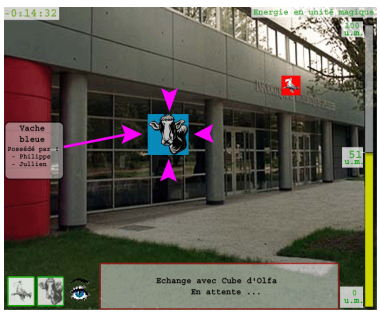
Multimodality
Combination of modalities

TROC: a game based on the technique of barter

M1 = (Magnetometer, orientation)

M2 = (GPS, location)

Complementarity of M1 and M2 for selecting an object



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Multimodality
Combination of modalities

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Multimodality
Combination of modalities

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Multimodality
Combination of modalities

- Several studies
  - UOM 94 / TYCOON 95 / CARE 95
- New combination space
  - Different schemas and aspects of combinations
  - 5 aspects: temporal, spatial, articulatory, syntactic and semantic
  - 5 schemas: [Allen 83]

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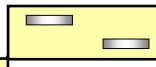
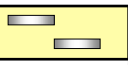
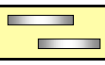
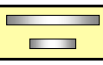
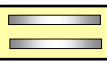
Multimodality:
Combination of modalities

Combination schemas

Combination aspects					
Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
Spatial	Separation	Adjacency	Intersection	Overlaid	Collocation
Articulatory	Independence	Fission	Fission Duplication	Partial Duplication	Total Duplication
Syntactic	Difference	Completion	Divergence	Extension	Twin
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy

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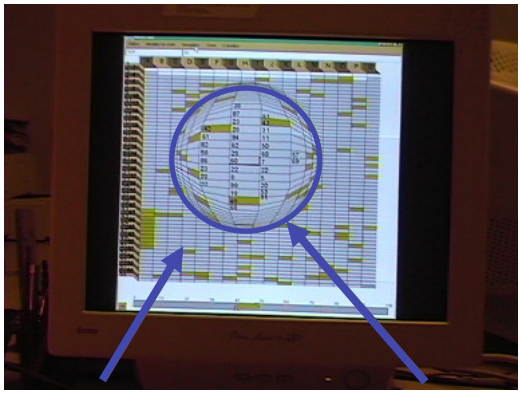
Multimodality: Combination of modalities

- Complementarity of output modalities



M1 = <screen, table> M2 = <screen, deformed table>

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Multimodality: Combination of modalities

- Combination of
  M1 = <screen, table> and
  M2 = <screen, deformed table>

Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
Spatial	Separation	Adjacency	Intersection	Overlaid	Collocation
Articulatory	Independence	Fission	Fission Duplication	Partial Duplication	Total Duplication
Syntactic	Difference	Completion	Divergence	Extension	Twin
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy

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Multimodality: Combination of modalities

- Puzzle

M1 = <screen, 2D image>

M2 = <screen, color>

M3 = <mini-screen, crosses>

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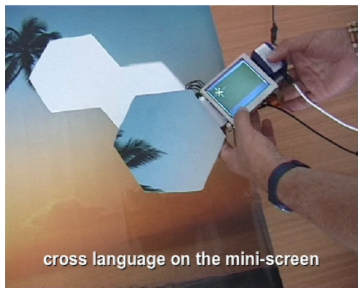
Multimodality: Combination of modalities

- Puzzle
  - *Video: PUZZLE-OUTPUT/Puzzle-CHI.avi*



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Multimodality: Combination of modalities

- Puzzle

M1 = <screen, 2D image>

M2 = <screen, color>

M3 = <mini-screen, crosses>

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Multimodality: Combination of modalities

- Combination of
  M2 = <screen, color> and
  M3 = <mini-screen, crosses>

Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
Spatial	Separation	Adjacency	Intersection	Overlaid	Collocation
Articulatory	Independence	Fission	Fission Duplication	Partial Duplication	Total Duplication
Syntactic	Difference	Completion	Divergence	Extension	Twin
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy

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Ergonomic design

Underlying concepts

Design space

Rules of thumb, heuristics

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Ergonomic design

- Heuristics for the design of multimodal interfaces
- Design Guidelines and Tools for the Design of Multimodal Interfaces
  - *See Supporting documents: Heuristics1.pdf*
- Guidelines for Multimodal UI design
  - *See Supporting documents: Heuristics2.pdf*

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Speech generation

- Speech **generation** is preferable when the
  - message is short.
  - message will not be referred to later.
  - messages deal with events in time.
  - message requires an immediate response.
  - visual channels of communication are overloaded.
  - environment is too brightly lit, too poorly lit, subject to severe vibration, or otherwise unsuitable for transmission of visual information.
  - user must be free to move around.

    - *Tentative guidelines for when NOT to use speech may be derived from these suggestions through negation.*
    - Michaelis, Paul Roller, and Wiggins, Richard H., (1982) reference in Heuristics1.pdf

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Speech input/output

- Spoken communication with machines (both input and output) may be advantageous:
  - when the user's hands or eyes are busy
  - when only limited keyboard and/or screen is available
  - when the user is disabled
  - when pronunciation is the subject matter of computer use
  - when natural language interaction is preferred

    - Cohen, P. R. & Oviatt, S. L. (1994) reference in Heuristics1.pdf

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Pen input

- Multifunctionality (text, digits, pointing, gestural marks, symbols,graphics, sketching & art, signatures, direct manipulation, etc.)
- Visual feedback, permanent record
- Preferred for spatial & graphic tasks, selection of objects, numeric & symbolic data, & signatures

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Pen input

- Precise spatial input (compared with speech, or even manual gesturing & touch)
- Easier for some populations (young children)
- Easy portability
- Direct input

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Eye-gaze

- Promising for passive control involving brief time intervals
- Promising as early indicator for monitoring user's interest
- Fast & highly sensitive, but often difficult to interpret
- Not under full conscious control- intentional looking mixed with periods of blank staring
- Easiest for some populations (young children, neurologically impaired)
- Good for hands busy tasks

- *Still exploratory use in HCI tasks, although technology maturing rapidly*
- *Eye-gaze applications: self-care applications for severely-impaired users (e.g., quadriplegics, MS, & other motorimpaired groups)*

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Eye-gaze

- Eye-gaze patterns: wrong assumptions
  - Users eyes stop to look at things
  - Users look at things intentionally
  - What users are looking at is an indication of what they're thinking
  - The eyes and hands manipulate things simultaneously
  - Eye trackers track eye movements reliably

- Gaze isn't a good mouse replacement!
- => Rake cursor (LIG-IIHM)

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Multimodal input/output

- *Supporting documents: heuristics2.pdf*
- A set of multimodal design principles that are founded in perception and cognition science

- Four general areas
  - Designing multimodal input and output
  - Adaptivity
  - Consistency
  - Feedback
  - Error prevention/handling

Multimodal input/output

- *Supporting documents: heuristics2.pdf*
- Designing multimodal input and output
  - Match output to acceptable user input style
    - if the user is constrained by a set grammar, do not design a virtual agent to use unconstrained natural language
- Adaptivity
  - Multimodal interfaces should adapt to the needs and abilities of different users, as well as different contexts of use. Dynamic adaptivity enables the interface to degrade gracefully by leveraging complementary and supplementary modalities according to changes in task and context.
    - Allowing gestures to augment or replace speech input in noisy environments, or for users with speech impairments

Multimodal input/output

- *Supporting documents: heuristics2.pdf*
- Consistency
  - System output independent of varying input modalities
    - the same keyword provides identical results whether user searches by typing or speaking
- Feedback
  - Users should know which modalities are available to them
- Error Prevention/Handling
  - If an error occurs, permit users to switch to a different modality

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Modality theory (O. Bernsen)

- Taxonomic analyses
  - Representational Input and output modalities are characterized in terms of a limited number basic features such as
    - *linguistic/nonlinguistic*
    - *analogue/non-analogue*
    - *arbitrary/nonarbitrary*
    - *static/dynamic*
- Modalities are characterized in terms of modality properties (MP) derived from the taxonomic analyses

  Supporting documents: heuristics1.pdf

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Modality theory (O. Bernsen)

- [MP1] Linguistic input/output modalities have interpretational scope, which makes them eminently suited for conveying abstract information. They are therefore unsuited for conveying high-specificity information including detailed information on spatial manipulation and location.
- [MP2] Linguistic input/output modalities, being unsuited for specifying detailed information on spatial manipulation, lack an adequate vocabulary for describing the manipulations.
- [MP3] Arbitrary input/output modalities impose a learning overhead which increases with the number of arbitrary items to be learned.
- [MP4] Acoustic input/output modalities are omnidirectional.
- [MP5] Acoustic input/output modalities do not require limb (including haptic) or visual activity.

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Modality theory (O. Bernsen)

- [MP6] Acoustic output modalities can be used to achieve saliency in low-acoustic environments. They degrade in proportion to competing noise levels.
- …
- [MP11] Speech input/output modalities in native or known languages have very high saliency.
- [MP12] Speech output modalities may complement graphic displays for ease of visual inspection.
- [MP13] Synthetic speech output modalities, being less intelligible than natural speech output, increase cognitive processing load.
- … [MP25]

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Design: Main points

- Design space for multimodal interaction
  - Characteristics of a modality
  - Composition space
- Mapping of functionalities onto modalities not always straightforward
  - Support from guidelines and tools
  - Experimental study

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Readings

- Bernsen, N. Modality Theory in support of multimodal interface design. Proceedings of Intelligent Multi-Media Multi-Modal Systems, (1994), pp. 37-44
- Bouchet, J., Nigay, L., Ganille, T. ICARE Software Components for Rapidly Developing Multimodal Interfaces. Proceedings of ICMI'04, ACM Press, pp. 251-258
  http://iihm.imag.fr/en/publication/
- Coutaz, J., et al. Four easy pieces for assessing the usability of multimodal interaction: The CARE properties, Proceedings of Interact'95, Chapman&Hall, pp. 115-120
  http://iihm.imag.fr/en/publication/
- Martin, J. C. TYCOON: Theoretical Framework and Software Tools for Multimodal Interfaces. Intelligence and Multimodality in Multimedia Interfaces, AAAI Press (1997)
- Nigay, L., Coutaz, J. The CARE Properties and Their Impact on Software Design. Intelligence and Multimodality in Multimedia Interfaces, (1997)
  http://iihm.imag.fr/en/publication/
- Vernier, F,. Nigay, L. A Framework for the Combination and Characterization of Output Modalities, Proceedings of DSV-IS2000, Springer-Verlag, pp. 32-48
  http://iihm.imag.fr/en/publication/
- OpenInterface http://www.oi-project.org/

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