

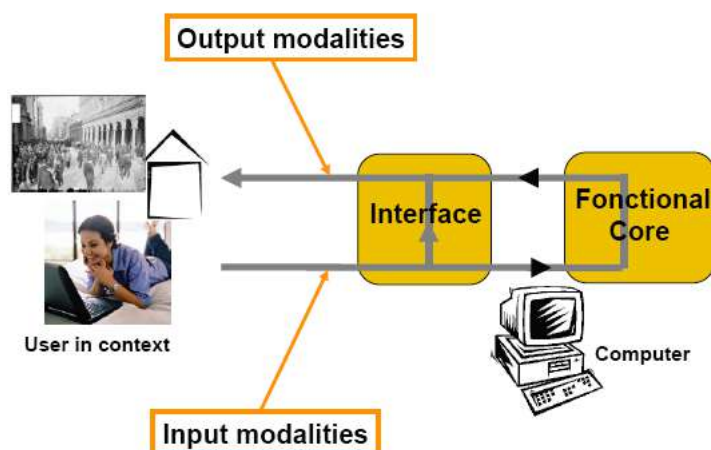
Multimodality: design

Underlying concepts
Design space
Rules of thumb, heuristics

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Underlying concepts



2

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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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Underlying concepts Definition of a modality

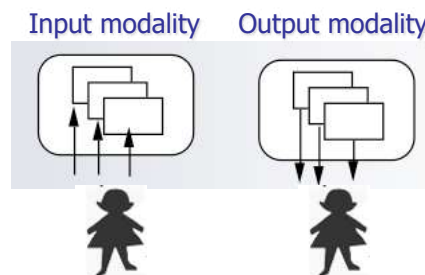
- Built-in cognitive capability of the system for interpretation and rendering
- Input modality
Interpretation function: sequence of transformations from input “raw information”
- Output modality
Rendering function: sequence of transformations to output “raw information”

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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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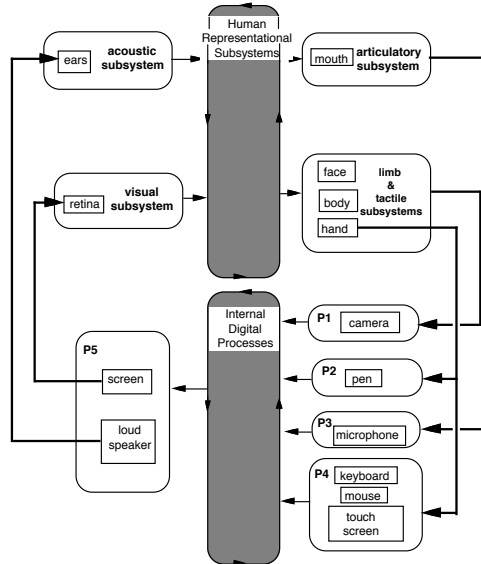
Definition of a modality

- 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



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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)
- Interaction paradigms such as perceptual User UI tangible UI, embodied UI and AR open a **vast world of possibilities**


- M1 = (microphone, natural language)
- M2 = (keyboard, command language)
- M3 = (mouse, direct manipulation)
- M4 = (smartphone, 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>

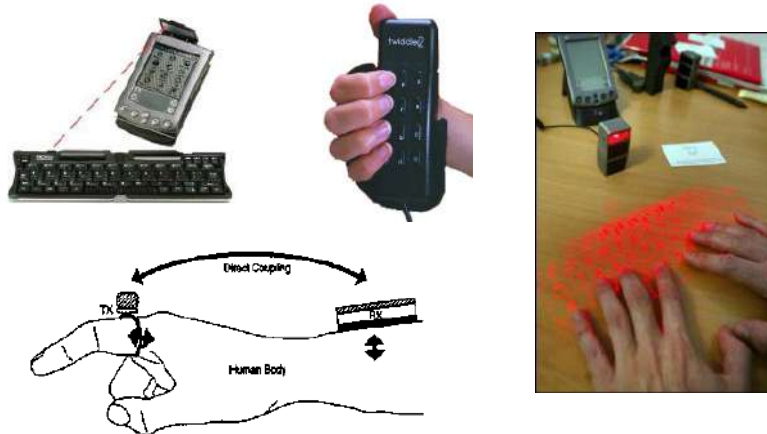
Speech = <  , natural language >



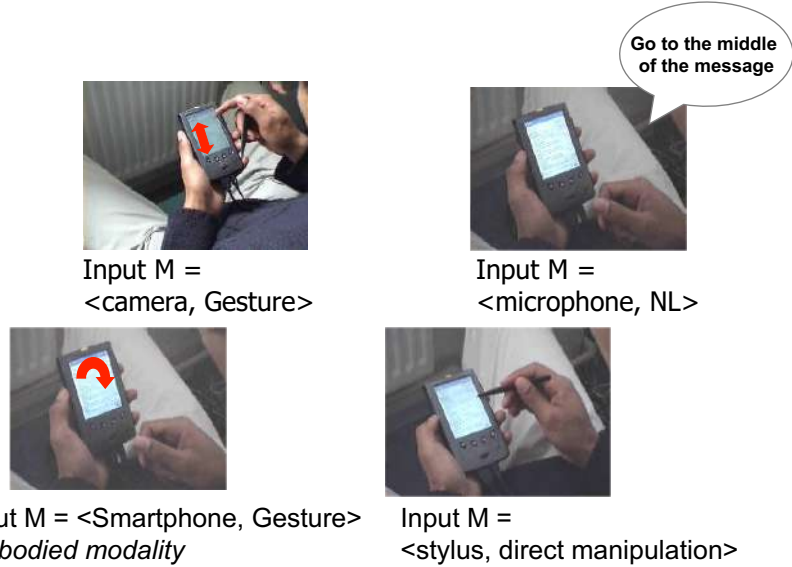
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Definition of a modality

- Input M = <device, text>



Definition of a modality



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

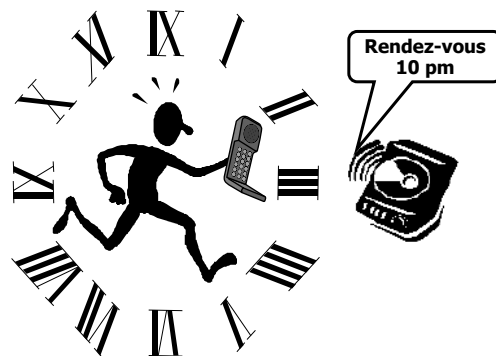
- OUTPUT Modality = $\langle d, I \rangle$
M = $\langle \text{HMD, 3D graphics} \rangle$



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Definition of a modality

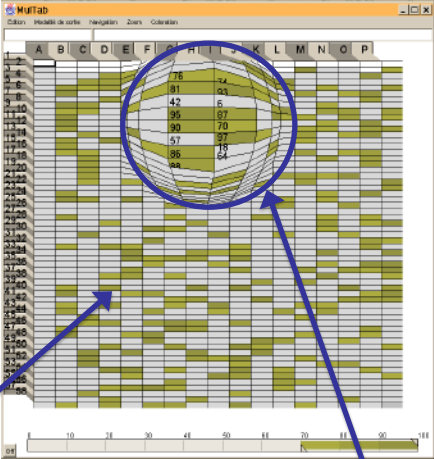
- Output M = $\langle \text{loudspeakers, NL} \rangle$
- 3D sound:



**Soundbeam
Neckset**

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Definition of a modality



Output M1 =
<screen, table>

Output M2 =
<screen, deformed table>

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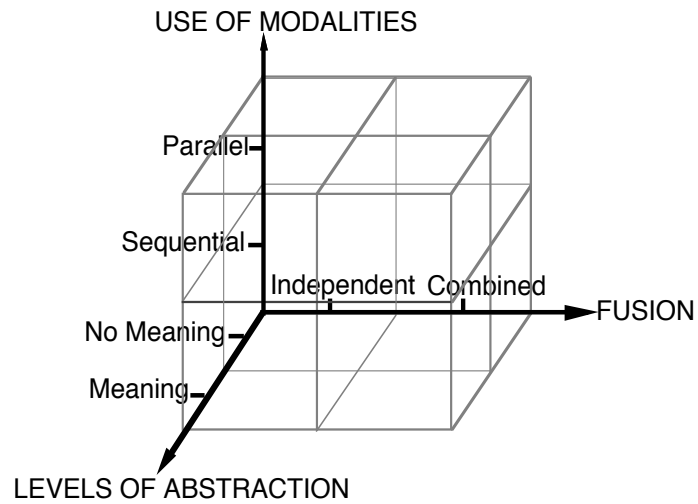
Underlying concepts

- 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

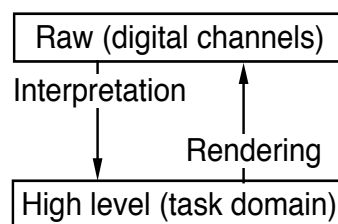


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Dimension 1: Levels of Abstraction

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 : 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

- Independent: (Absence of fusion)
Independent interpretation/rendering process for each modality
- Combined: (Presence of fusion)
Fusion of data expressed using different modalities

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Dimension 3: Fusion

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

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Dimension 3: Fusion

- **Lowest level: chunks from distinct modalities**
- Fusion of data expressed using different modalities
 - "Put that there" paradigm



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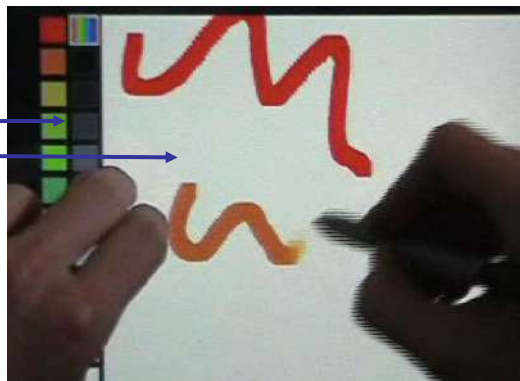
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Dimension 3: Fusion

- Higher levels: chunks from distinct contexts

– Fusion of events

- Palette
- Drawing area

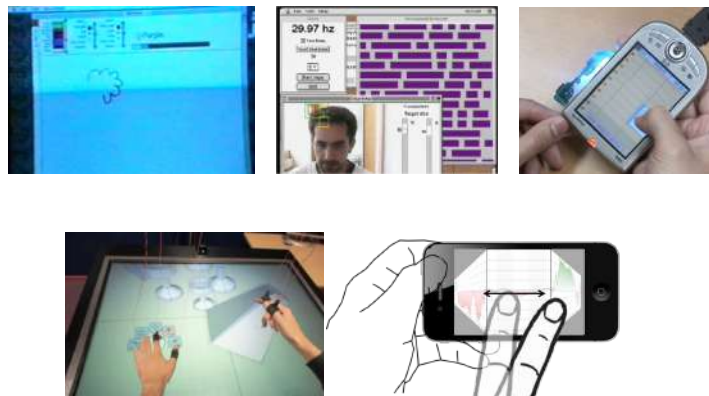


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Dimension 3: Fusion

- Higher levels: chunks from distinct contexts



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Multimodal versus multimedia

A multimodal system:





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

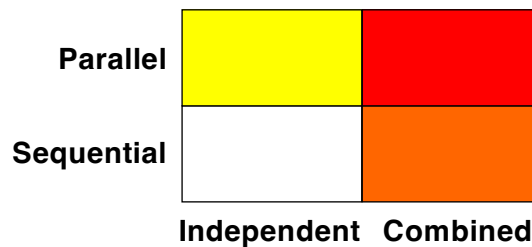
=> Four types of multimodal systems

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Multimodal system: four types CASE

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



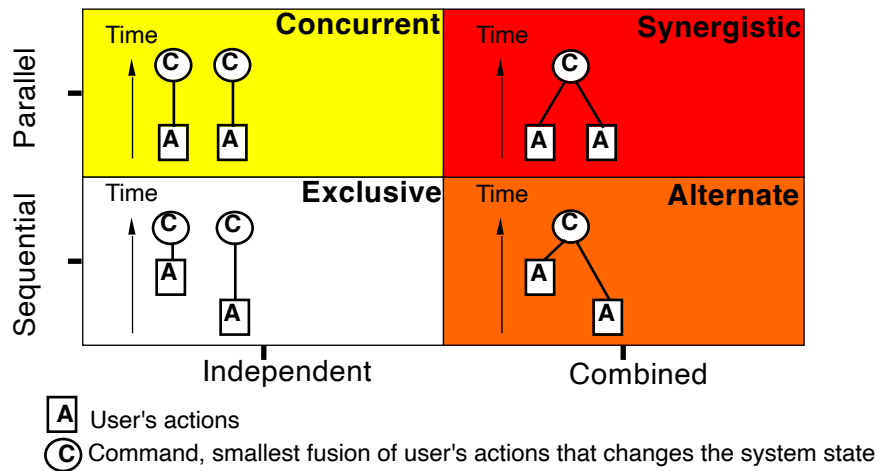
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Multimodal system: four types

A multimodal system:

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



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Multimodality: design

Underlying concepts

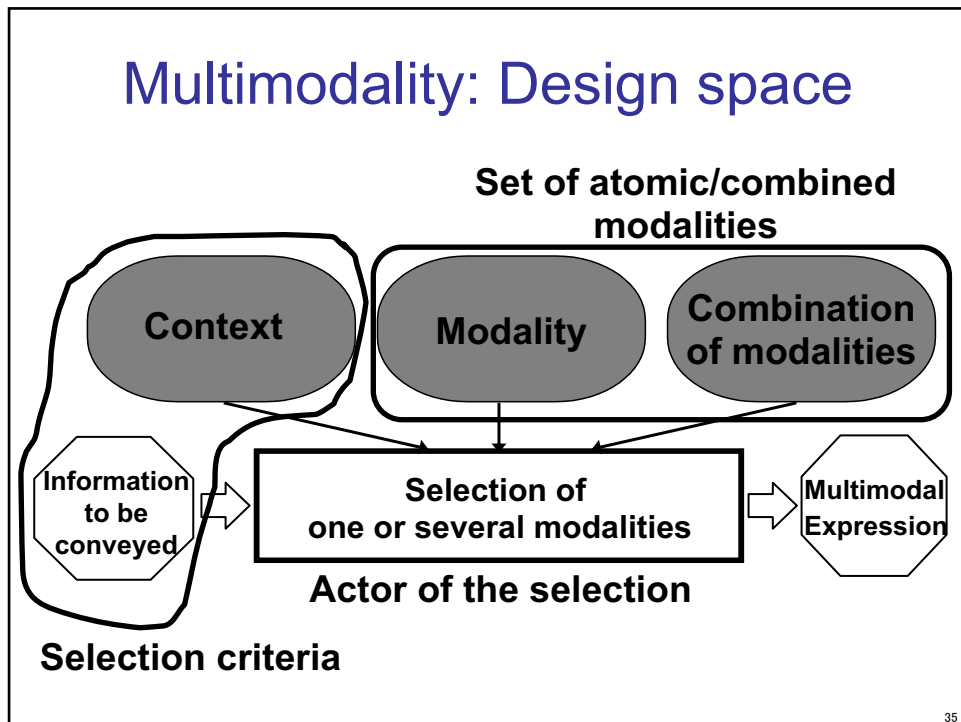
Design space

Rules of thumb, heuristics

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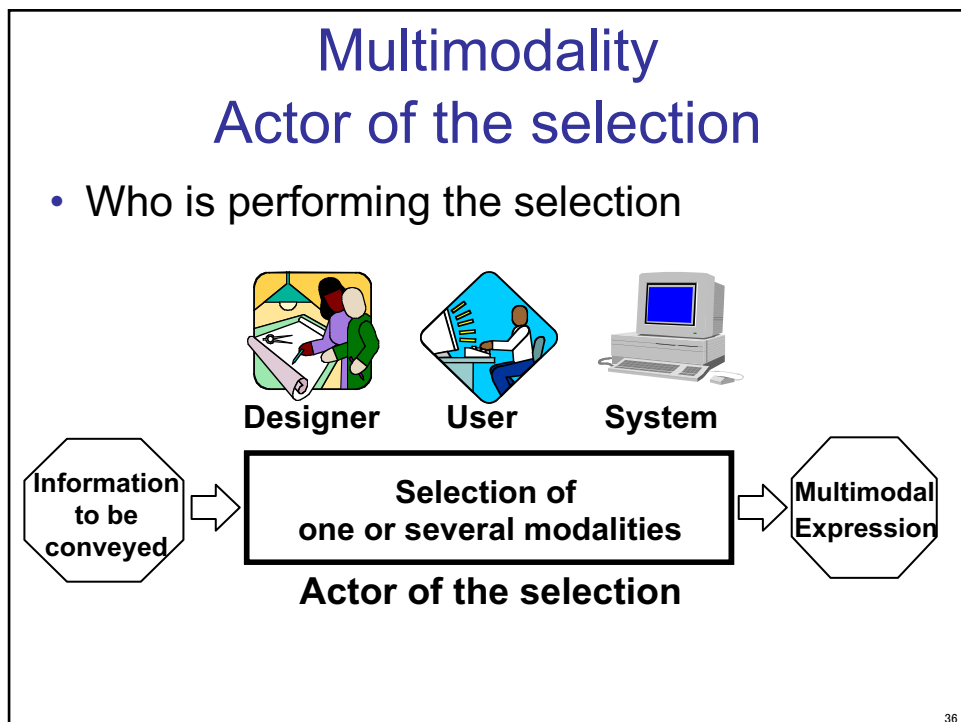
Multimodality: Design space



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Multimodality Actor of the selection

- Who is performing the selection



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Multimodality

Actor of the selection

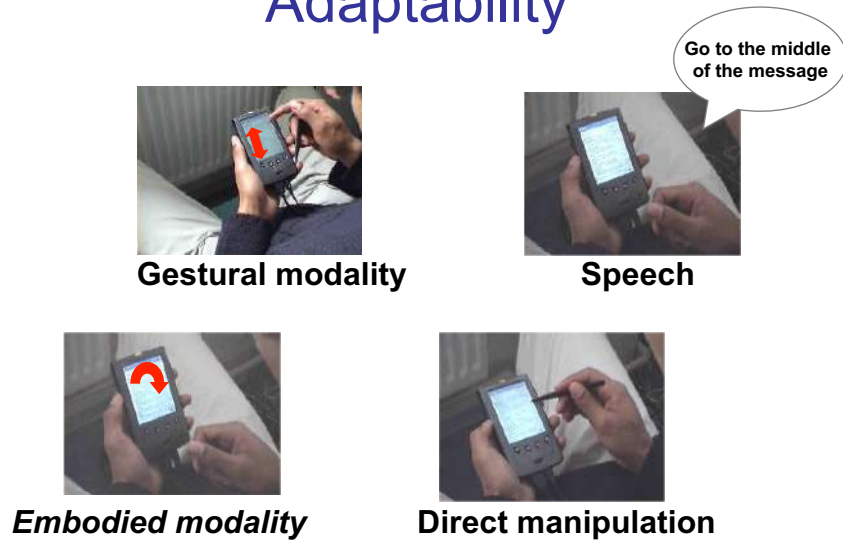


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Multimodality

Adaptability

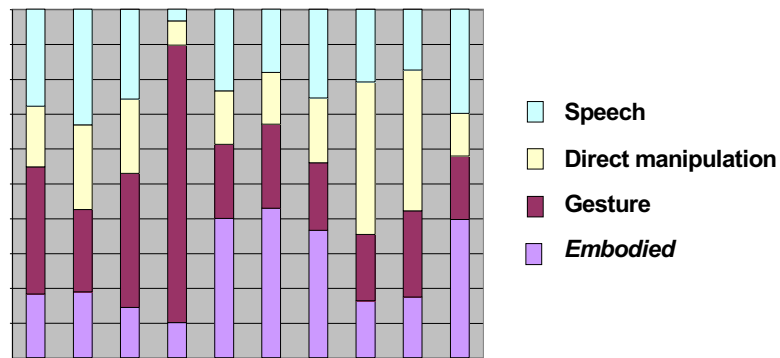


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Multimodality Adaptability

- Usage of the modalities
- All sessions / All subjects



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Multimodality Adaptativity

- Selection of the modalities by the system
- Context-aware systems (passive modality)



Ring

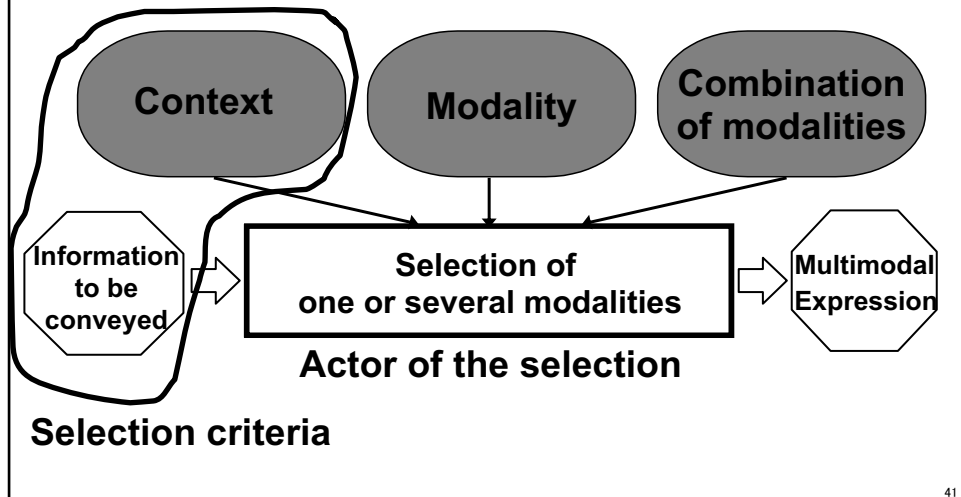


Vibration

40

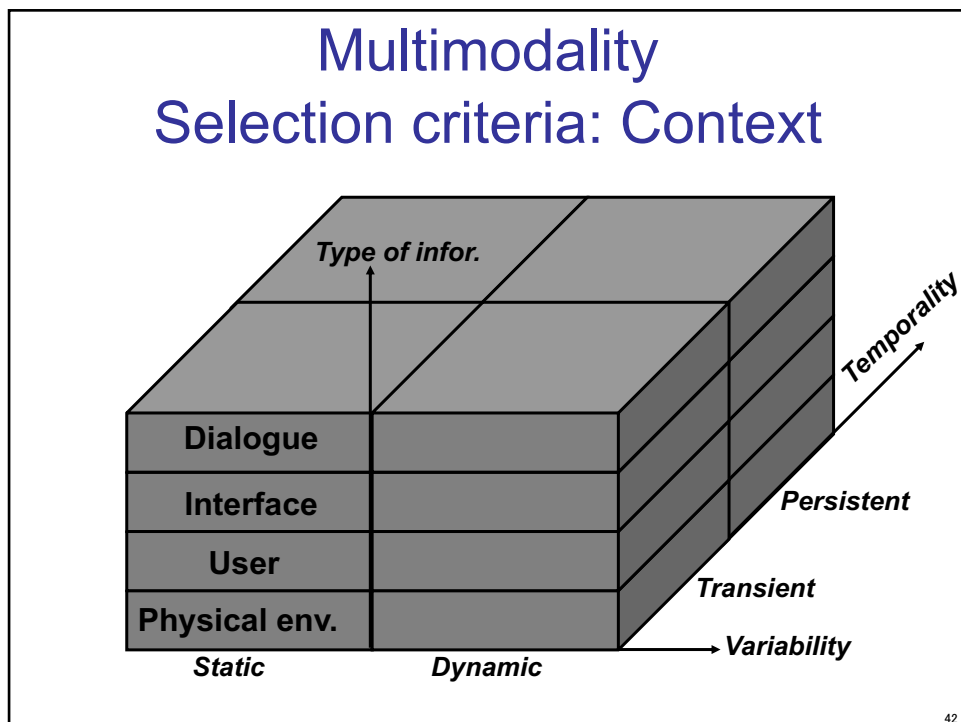
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Multimodality: Design space



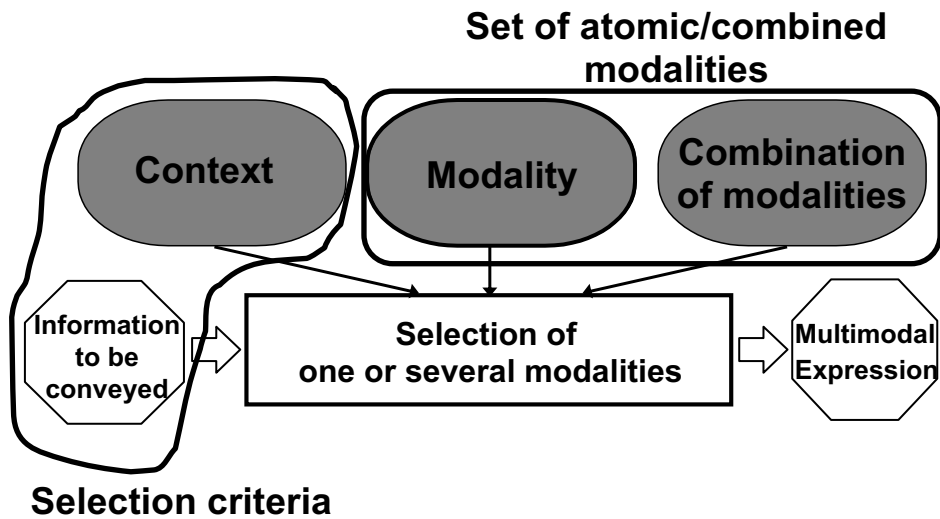
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Multimodality Selection criteria: Context



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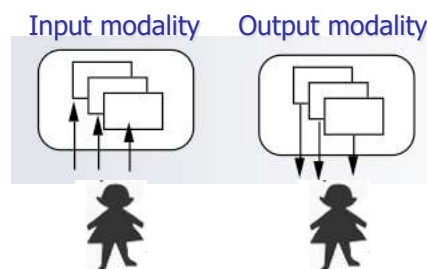
Multimodality: Design space



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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

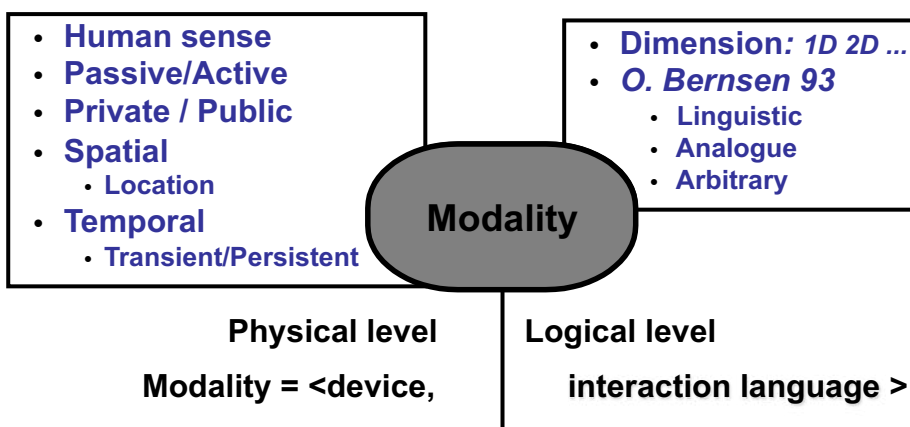
- **ACTIVE MODALITIES**
 - For inputs, active modalities are used by the user to issue a command to the computer such as a pedal to move a laparoscope in a CAS system.
- **PASSIVE - IMPLICIT MODALITIES**
 - Passive modalities are used to capture relevant information for enhancing the realization of the 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



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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



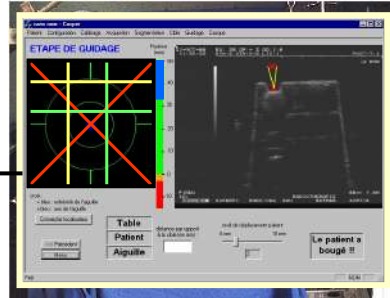
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Multimodality

Characterisation of a modality

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



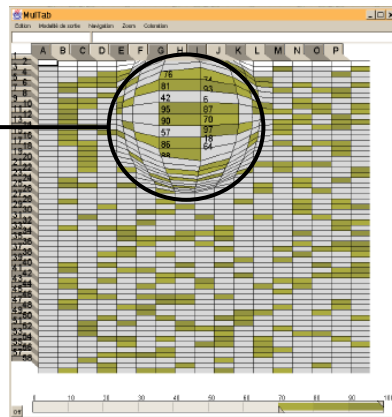
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Multimodality

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

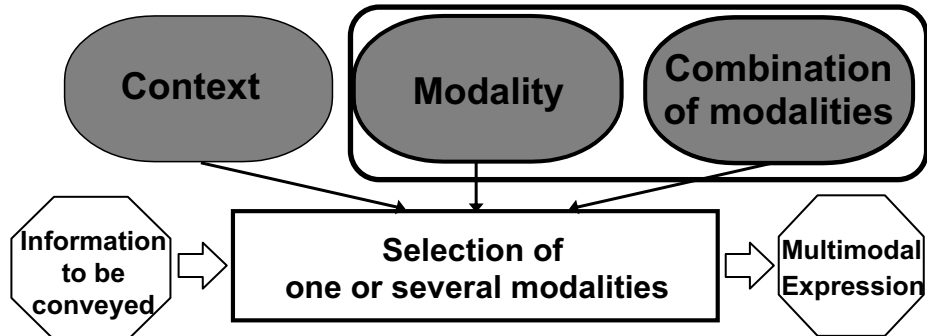
- **Physical level**
 - Human manipulation
 - Spatial: Location = desk
 - Temporal: Persistent
- **Logical level**
 - 3D gesture
 - Analogue
 - Non Arbitrary



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Multimodality: Design space

Set of atomic/combined modalities



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Multimodality

Combination of modalities

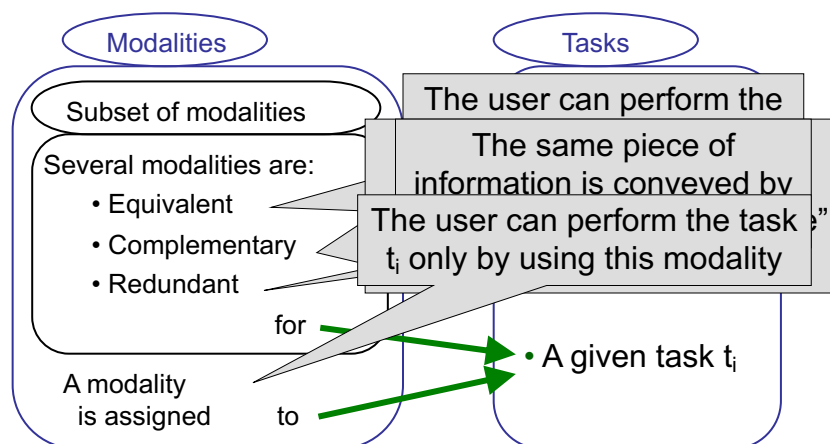
- CARE properties
 - Relationships between Devices, Interaction languages and Tasks
 - C : Complementarity
 - A : Assignment
 - R : Redundancy
 - E : Equivalence

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Multimodality

Combination of modalities



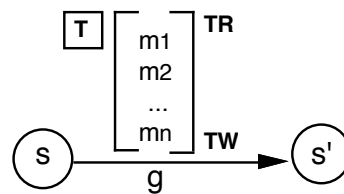
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Multimodality

Combination of modalities

- The formal expression of the CARE properties relies on the notions of state, goal, modality, and temporal relationships
 - Modality $m_i = \langle d, l \rangle$ = an interaction method that an agent (user, system) can use to reach a goal.
 - Goal g = a state s' that an agent intends to reach from s using modalities m_1, m_n
 - TR = temporal relationships between the use of modalities m_1, \dots, m_n (parallelism, sequentiality, cardinality) = // | ; | 1
 - TW = temporal window within which the modalities are used
 - $T = C | A | R | E$ = Complementarity, Assignment, Redundancy, Equivalence

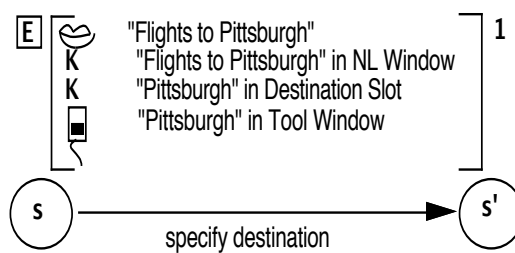


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Equivalence

- Modalities of set M are equivalent for reaching s' from s , if it is necessary and sufficient to use any one of the modalities



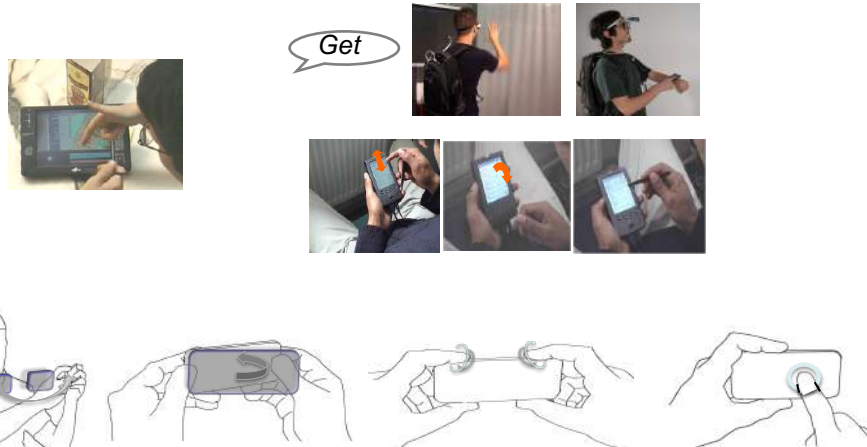
- Equivalence (s, M, s')
 \Leftrightarrow
 $(\text{Card}(M) > 1) \wedge (\forall m \in M \text{ Reach}(s, m, s'))$

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Equivalence

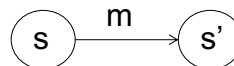
- Modalities of set M are equivalent for reaching s' from s, if it is necessary and sufficient to use any one of the modalities



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Assignment

- In contrast to equivalence, assignment expresses the absence of choice.
- Modality m is assigned in state s to reach s', if no other modality can be used to reach s' from s



- Assignment (s, m, s')

⇔

Reach (s, m, s')

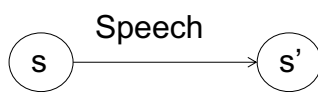
$\wedge (\forall m' \in M. \text{Reach}(s, m', s') \Rightarrow m' = m)$

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Assignment

- Modality m is assigned in state s to reach s' , if no other modality can be used to reach s' from s



https://store.google.com/uk/product/google_home

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Assignment

User conditions

- static — in motion
- private — public
- poor — rich touch interaction

Output

- + visual
- + audio

Input

- + visual
- + audio

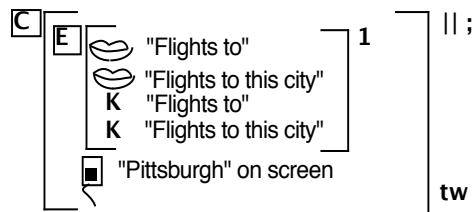
/ Audio only surfaces

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Complementarity

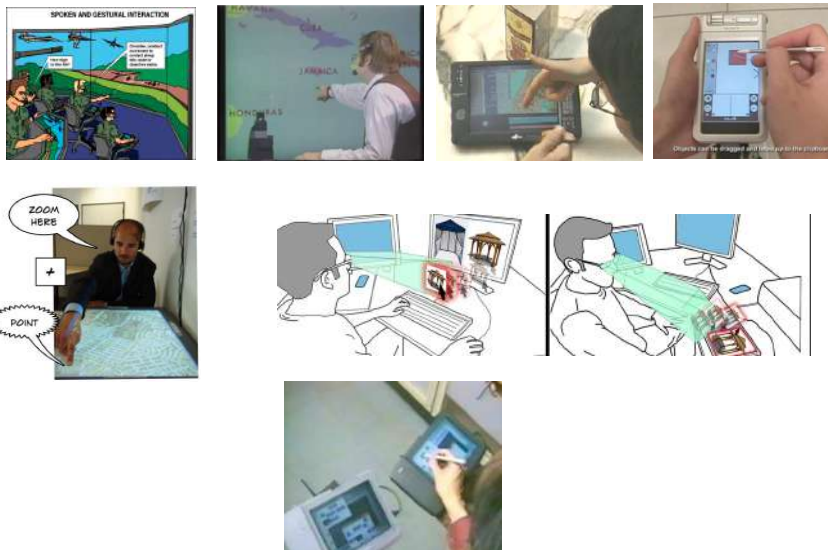
- Modalities of a set M must be used in a complementary way to reach state s' from state s within a temporal window, if all of them must be used to reach s' from s, i.e., none of them taken individually can cover the target state. (fusion required)



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Complementarity

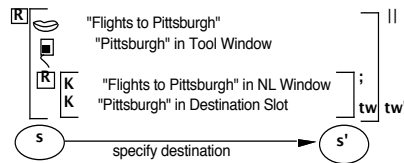


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Redundancy

- 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.



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Redundancy

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Multimodality

Combination of modalities

- CARE : relationships between modalities and tasks
- => Semantic relationships

- Adding the temporal aspect when two modalities are used

- **2 aspects: temporal and semantic**
- **5 schemas: [Allen 83]**

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Multimodality:

Combination of modalities

Combination schemas

Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy

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Multimodality: Combination of modalities

Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy

Parallel	Concurrent	Synergic
Sequential	Exclusive	Alternate
	Independent	Combined

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Multimodality: Combination of modalities

Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy

Parallel	Concurrent	Synergic
Sequential	Exclusive	Alternate
	Independent	Combined

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Multimodality: Combination of modalities

Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy

Parallel	Concurrent	Synergic
Sequential	Exclusive	Alternate
	Independent	Combined

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Multimodality: Combination of modalities

Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy

Parallel	Concurrent	Synergic
Sequential	Exclusive	Alternate
	Independent	Combined

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Multimodality: Combination of modalities

Adding the **spatial aspect**
when two modalities are used

Combination schemas

Combination aspects	Combination schemas					
	Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
	Spatial	Separation	Adjacency	Intersection	Overlaid	Collocation
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy	

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Multimodality: Combination of modalities

Combination schemas

Combination aspects	Combination schemas					
	Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
	Spatial	Separation	Adjacency	Intersection	Overlaid	Collocation
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



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>

Combination schemas

Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
Spatial	Separation	Adjacency	Intersection	Overlaid	Collocation
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy

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Multimodality

Combination of modalities

- CARE properties

- C : Complementarity
- A : Assignment
- R : Redundancy
- E : Equivalence

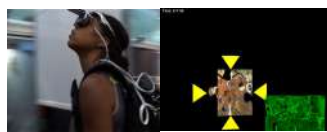
Combination schemas

Temporal	Anachronism	Sequence	Concomitance	Coincidence	Parallelism
Spatial	Separation	Adjacency	Intersection	Overlaid	Collocation
Semantic	Concurrency	Complementarity	Complementarity & Redundancy	Partial Redundancy	Total Redundancy

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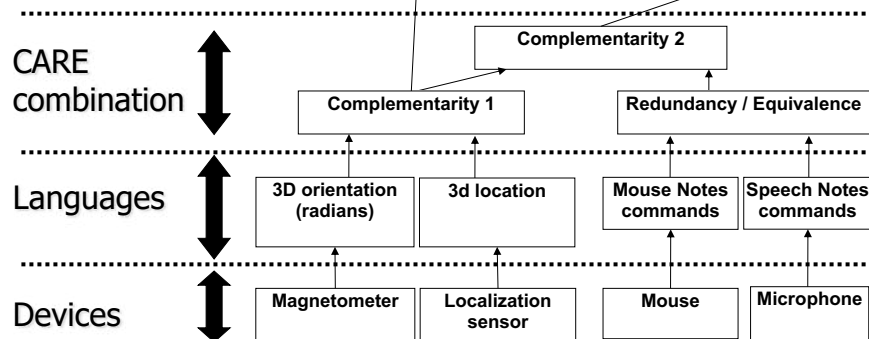
Multimodality

Combination of modalities



Task:
Update position & orientation of User

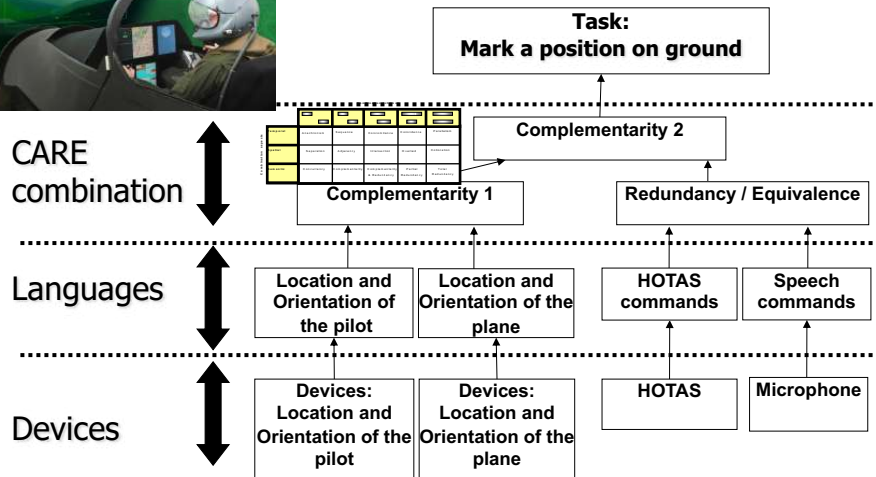
Tasks:
Manipulation of Note
(create, pick, and remove)



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Multimodality

Combination of modalities



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Multimodality

Combination of modalities

- CARE properties
- TYCOON design space

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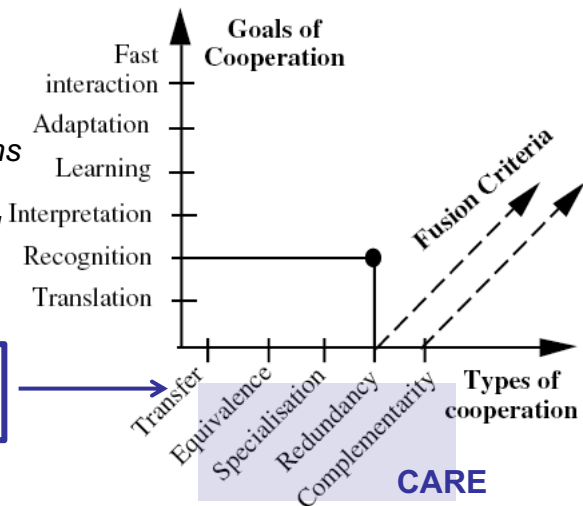
Multimodality

Combination of modalities

- TYCOON

When several modalities cooperate by transfer, this means that a chunk of information produced by a modality is used by another modality


TRANSFER

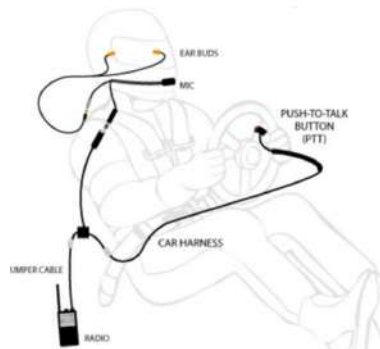


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Multimodality

Transfer of modalities

- One modality is used to activate another modality
- Push-To-Talk
- <button, press/release> (active modality)
-  <microphone, speech command> (active modality)



<https://www.sampsonracing.com/2-Way-Hole-Mount-PTT-with-Mounting-Bracket-p/p0520.htm>

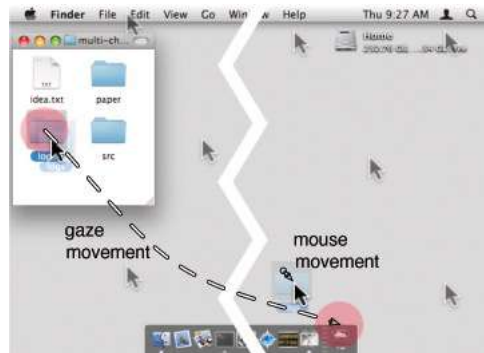
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Multimodality

Transfer of modalities

- Eye-tracking is used to select the cursor manipulated by the mouse
- <eye-tracking, 2D position> (*passive modality*)
➡ <mouse, direct manipulation> (*active modality*)

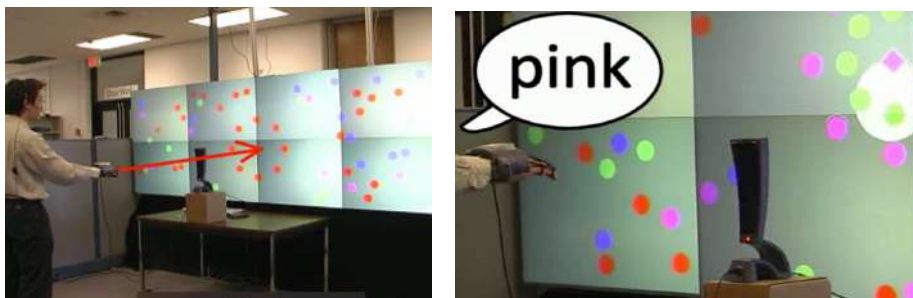


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Multimodality

Transfer of modalities

- Speech is used to modify the behavior of the pointing technique
- <Microphone, name of a color> (*active modality*)
➡ <3D gesture, pointing-bubble cursor> (*active modality*)



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Multimodality: design

Underlying concepts

Design space

Rules of thumb, heuristics

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Multimodal input/output

- *Supporting documents: heuristics.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

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Multimodal input/output

- *Supporting documents: heuristics.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

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Multimodal input/output

- *Supporting documents: heuristics.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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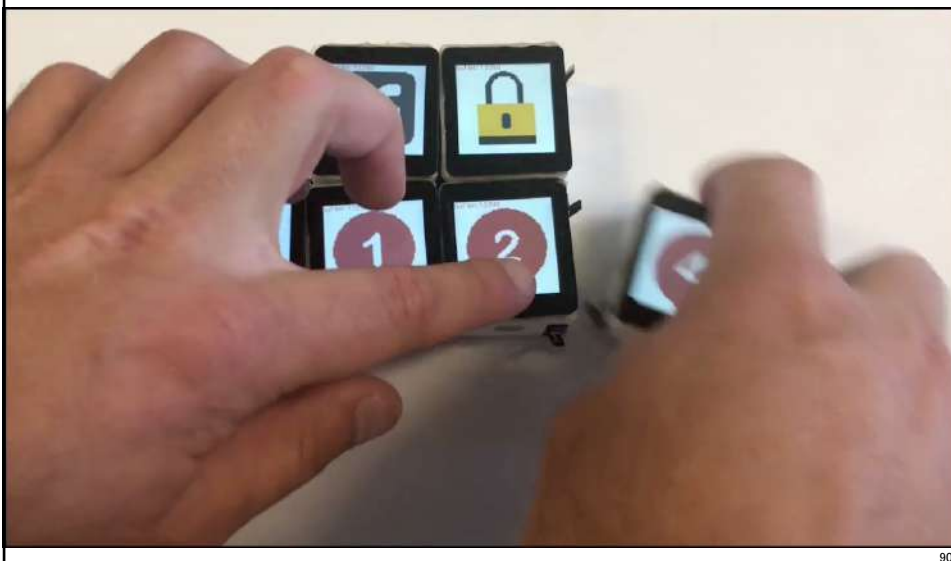
Design: Main points

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

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One research avenue: reconfigurable device

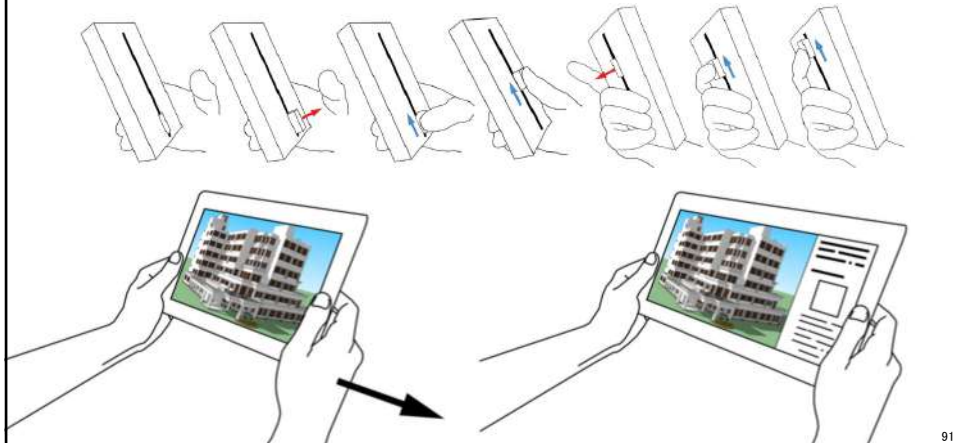


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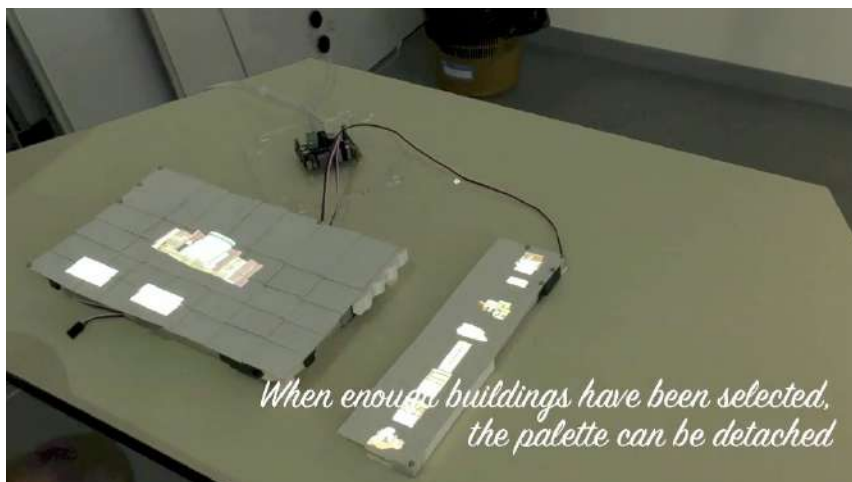
One research avenue: shape-changing UI

- Modality <device, language>
with a deformable device



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One research avenue: shape-changing UI



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Readings

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