Laurence Nigay
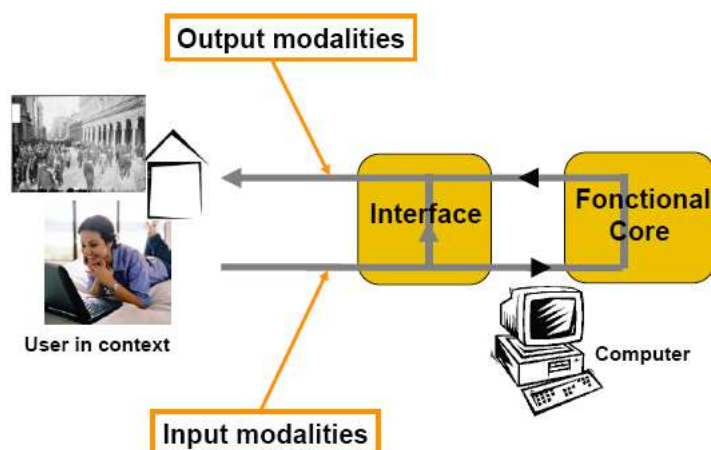Laurence.Nigay@univ-grenoble-alpes.fr

Multimodality: design

Underlying concepts
Design space
Rules of thumb, heuristics

1

Underlying concepts

2

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)

3

3

Underlying concepts
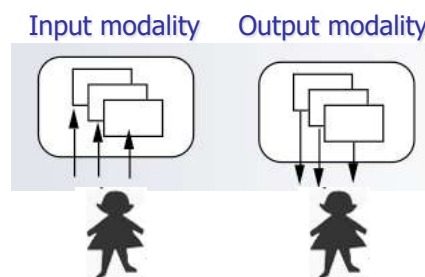# Definition of a modality

- 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"

4

4

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
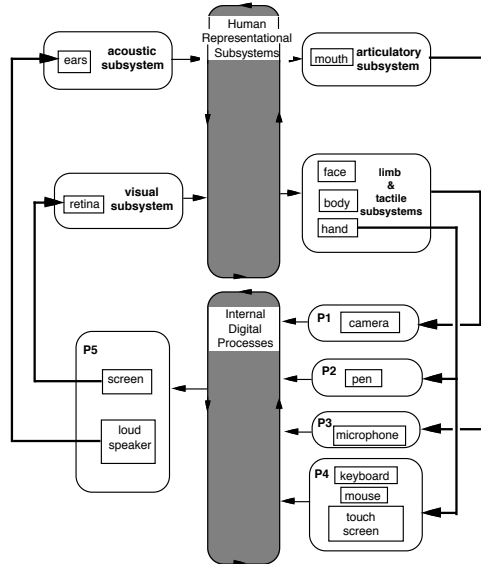
Input modality   Output modality

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

Human Representational Subsystems

ears	acoustic subsystem	
		mouth articulatory subsystem
retina	visual subsystem	
		face / body / hand — limb & tactile subsystems

Internal Digital Processes

- P1 camera
- P2 pen
- P3 microphone
- P4 keyboard / mouse / touch screen
- P5 screen / loud speaker

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)

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)*
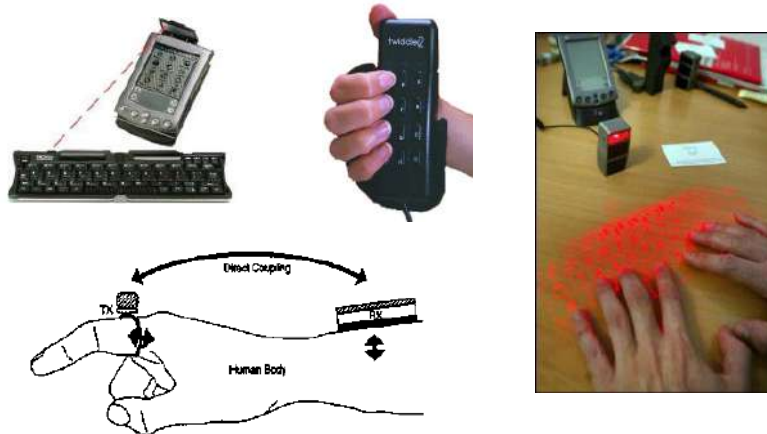
Definition of a modality

- Input Modality = <d, l>

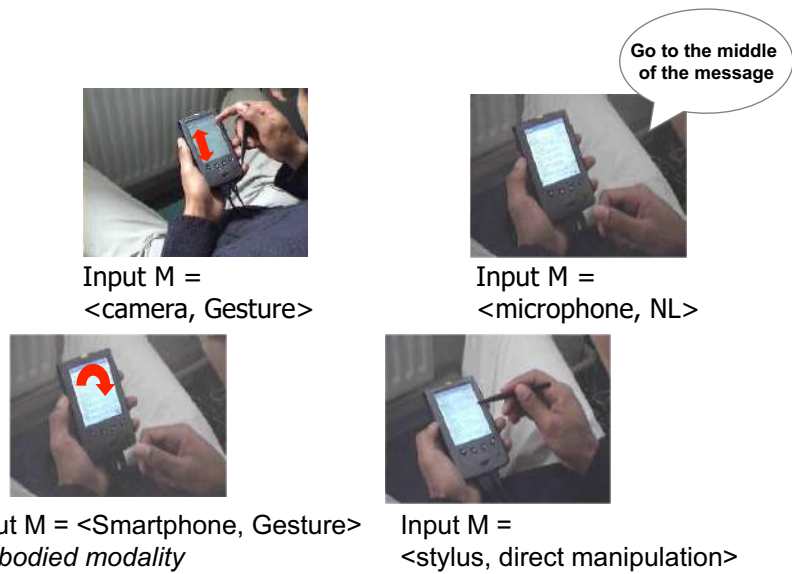 Speech = < 🎤 , natural language>

  Flights from Pittsburgh to Boston

Definition of a modality

- Input M = <device, text>

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Definition of a modality

Go to the middle of the message

Input M = <camera, Gesture>

Input M = <microphone, NL>

Input M = <Smartphone, 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>

Definition of a modality

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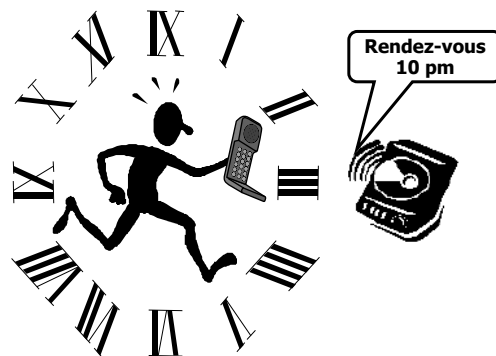- M1 = <GPS, localization>
- M2= <magnetometer, orientation>

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Definition of a modality

- OUTPUT Modality = <d, l>

  M = <HMD, 3D graphics>

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Definition of a modality

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

Rendez-vous 10 pm

Soundbeam Neckset

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Definition of a modality

Output M1 =
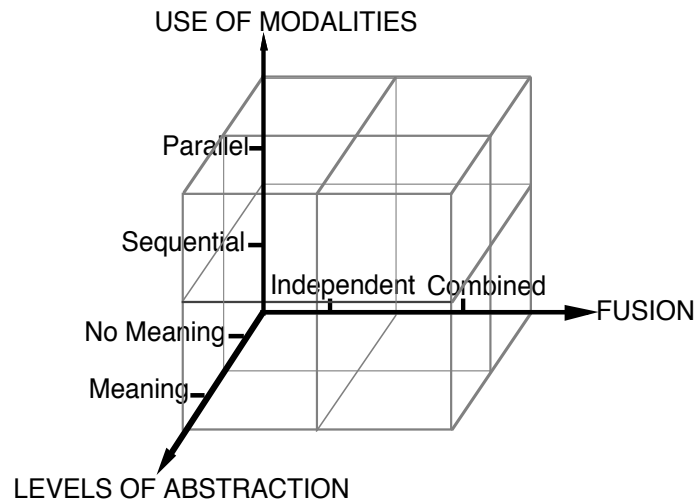<screen, table>

Output M2 =
<screen, deformed table>

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
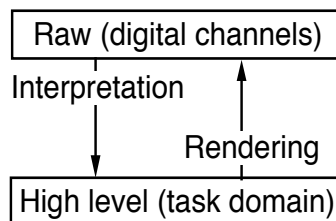 - 4. Granularity of concurrency

Underlying concepts

USE OF MODALITIES

Parallel

Sequential

Independent Combined

No Meaning ──────── FUSION

Meaning

LEVELS OF ABSTRACTION

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Dimension 1: Levels of Abstraction

Expresses the variety of representations supported by the system:

| Raw (digital channels) |

Interpretation

Rendering

| High level (task domain) |

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

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

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 dictinct contexts

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Dimension 3: Fusion

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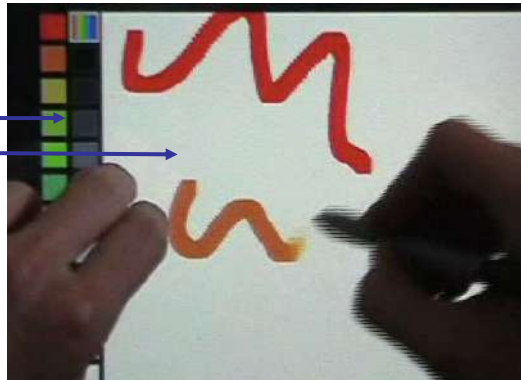 - "Put that there" paradigm

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Dimension 3: Fusion

- **Higher levels: chunks from dictinct contexts**

  – Fusion of events
    - Palette
    - Drawing area

Dimension 3: Fusion

- **Higher levels: chunks from distinct contexts**

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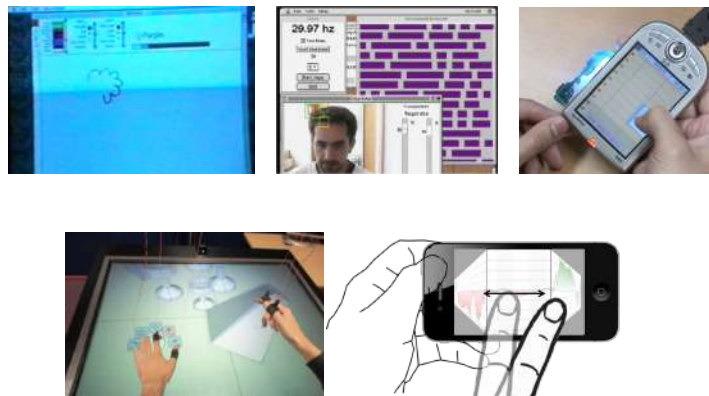
Multimodal versus multimedia

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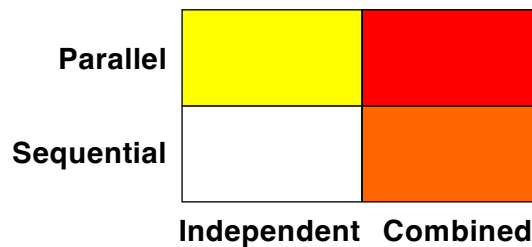
**Value "Meaning"
along the axis "Levels of
Abstraction"**

=> Four types of multimodal systems

Multimodal system: four types
CASE

Exclusive: (Sequential, Independent)

Alternate: (Sequential, Combined)

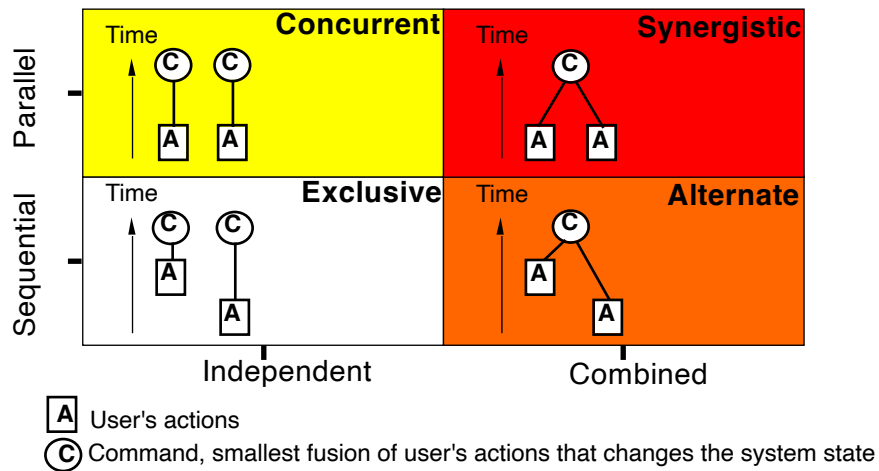**Concurrent: (Parallel, Independent)**

Synergic: (Parallel, Combined)

	Independent	**Combined**
Parallel	(yellow)	(red)
Sequential	(white)	(orange)

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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 |

Multimodality: design

Underlying concepts
Design space
Rules of thumb, heuristics

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Multimodality: Design space

Set of atomic/combined modalities

Context

Modality

Combination of modalities

Information to be conveyed

Selection of one or several modalities

Actor of the selection

Multimodal Expression

Selection criteria

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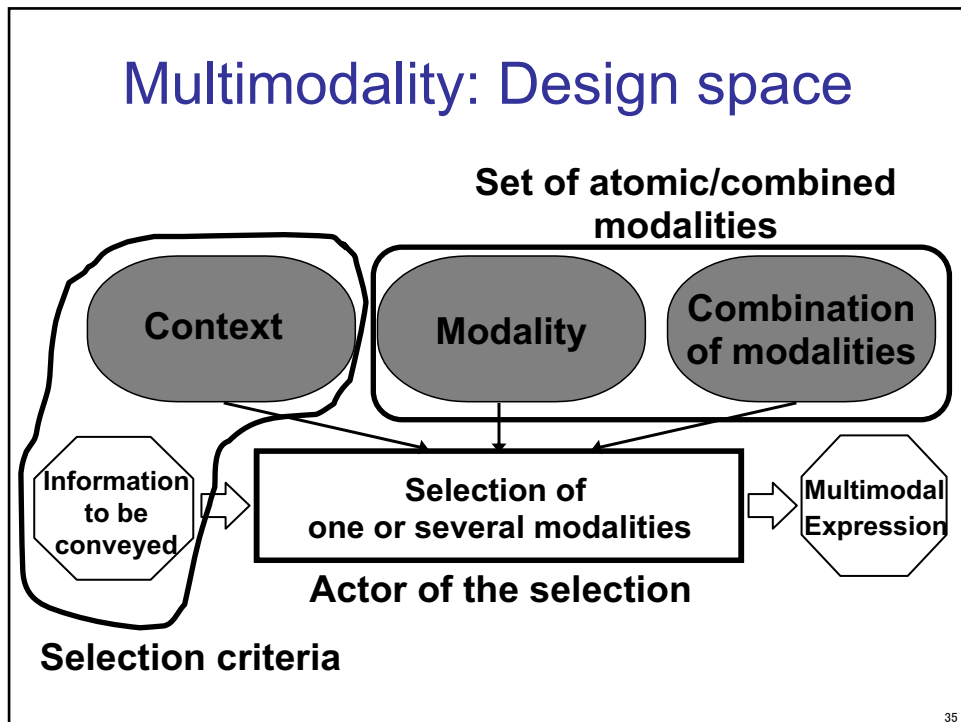
35

Multimodality
Actor of the selection

- Who is performing the selection

Designer　　**User**　　**System**

Information to be conveyed

Selection of one or several modalities

Actor of the selection

Multimodal Expression

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Multimodality
Actor of the selection

No adaptation

Adaptability

Adaptivity

Selection by the designer

Selection by the user

Selection by the system

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Multimodality
Adaptability

Go to the middle of the message

Gestural modality

Speech

Embodied modality

Direct manipulation

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Multimodality
Adaptability

- Usage of the modalities
- All sessions / All subjects

- Speech
- Direct manipulation
- Gesture
- *Embodied*
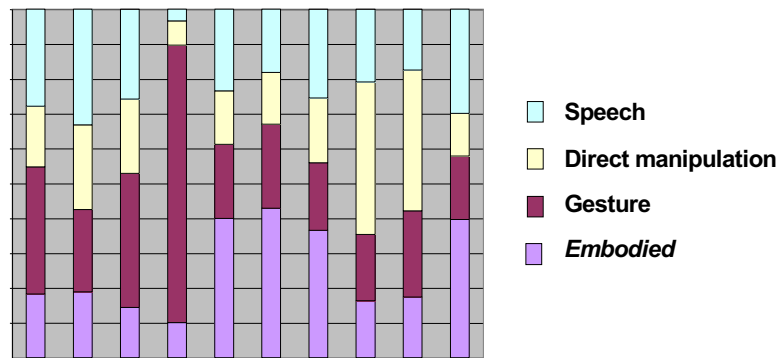
39

Multimodality
Adaptativity

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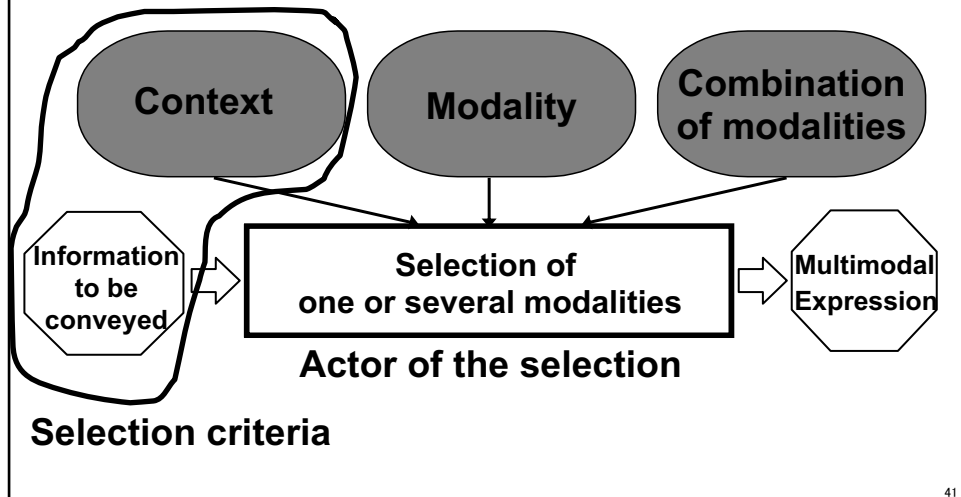- Context-aware systems (passive modality)
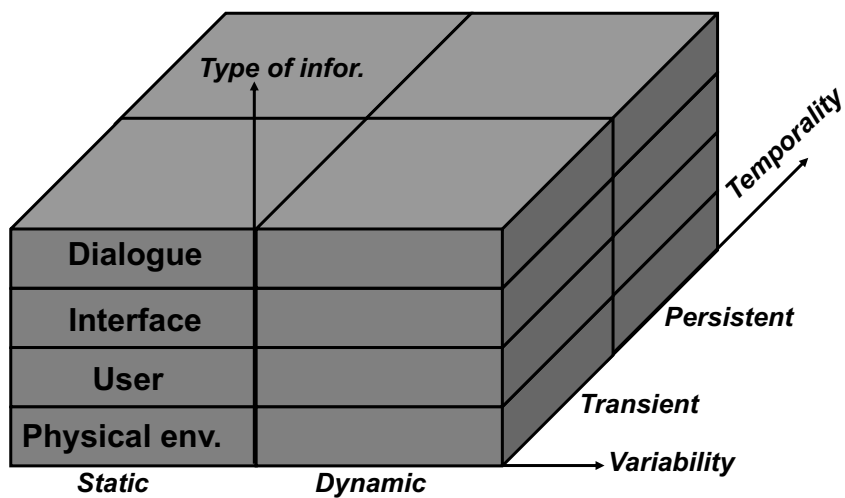

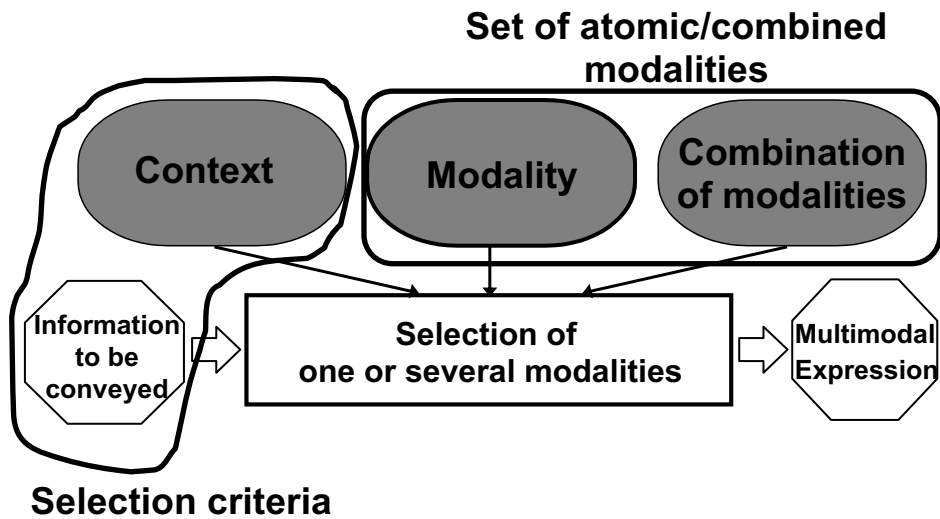
Ring

Vibration

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Multimodality: Design space

Context   **Modality**   **Combination of modalities**

Information to be conveyed → **Selection of one or several modalities** → **Multimodal Expression**

Actor of the selection

Selection criteria

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Multimodality
Selection criteria: Context

Type of infor.

Temporality

Dialogue

Interface

Persistent

User

Physical env.

Transient

Variability

Static   *Dynamic*

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Multimodality: Design space

Set of atomic/combined modalities

Context

Modality

Combination of modalities

Information to be conveyed

Selection of one or several modalities

Multimodal Expression

Selection criteria

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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

Input modality   Output modality

44
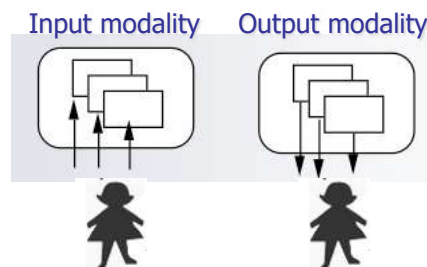
44

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**

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

Modality

Physical level   **Logical level**
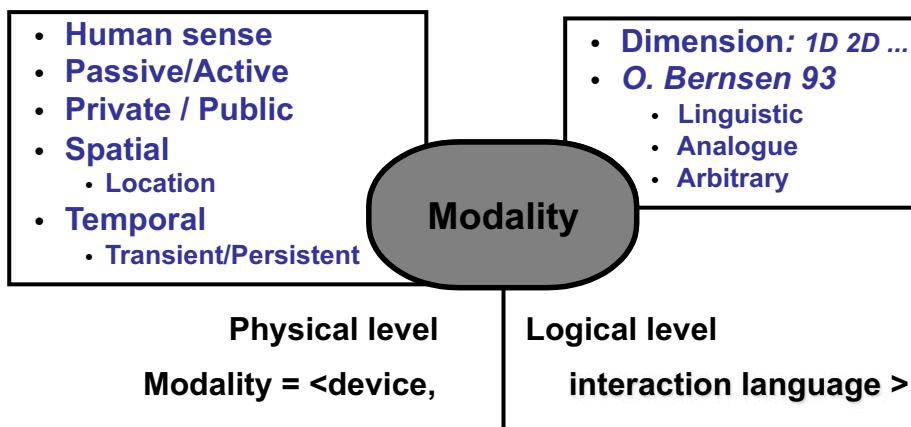
Modality = <device,   **interaction language >**

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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**

50
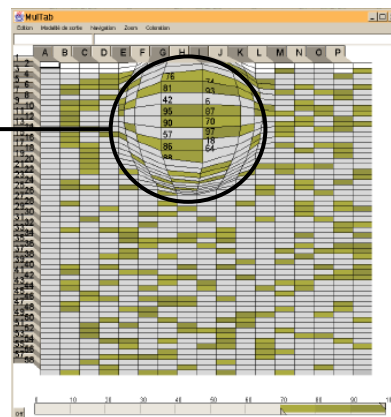
50

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

Context

Modality

Combination of modalities

Information to be conveyed

Selection of one or several modalities

Multimodal Expression

52
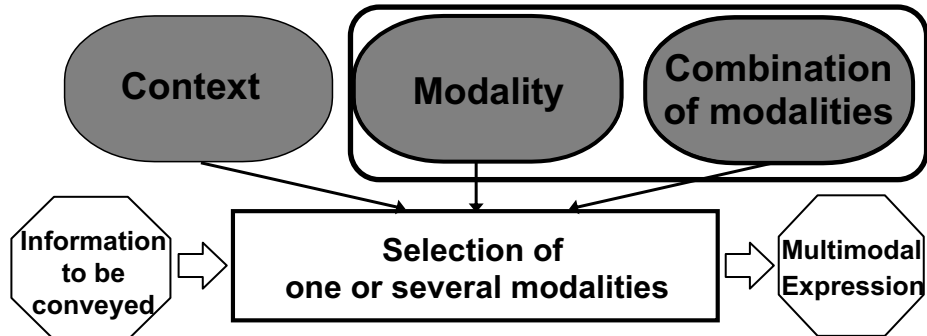
52

Multimodality
Combination of modalities

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

Multimodality
Combination of modalities

Modalities

Tasks

Subset of modalities

The user can perform the

Several modalities are:
- Equivalent
- Complementary
- Redundant

for

A modality is assigned to

The same piece of information is conveyed by

The user can perform the task t_i only by using this modality

- A given task t_i

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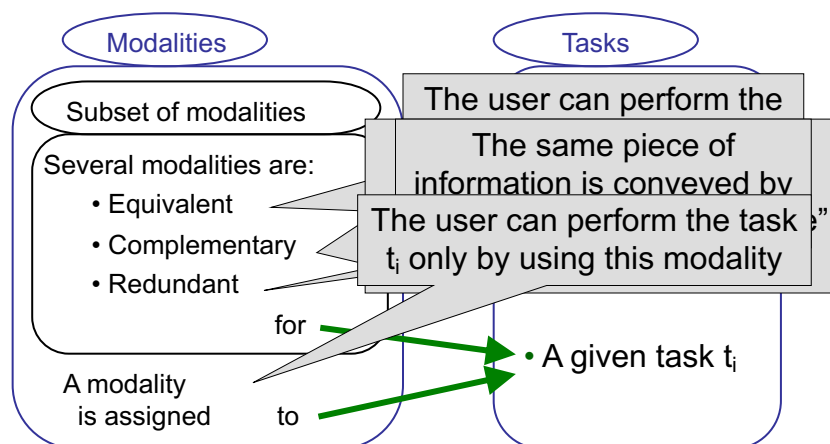
Multimodality
Combination of modalities

- The formal expression of the CARE properties relies on the notions of state, goal, modality, and temporal relationships
  - Modality $m_i = <d, l>$ = 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 m1, .. Mn (parallelism, sequentiality, cardinality) = // | ; | 1
  - TW = temporal window within which the modalities are used
  - T = C | A | R | E = Complementarity, Assignment, Redundancy, Equivalence
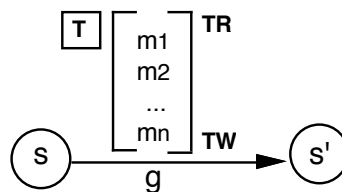
Equivalence

- Modalities of set M are equivalent for reaching s' from s, if it is necessary and sufficient to use any one of the modalities
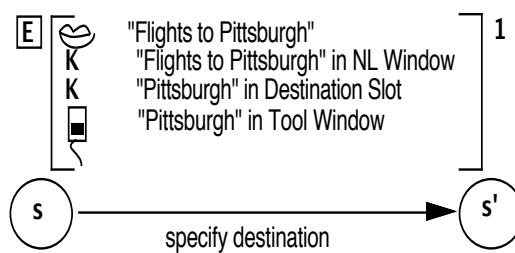
- Equivalence (s, M, s')
  $\Leftrightarrow$
  $(Card(M) > 1) \wedge (\forall m \in M \ Reach \ (s, m, s'))$

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
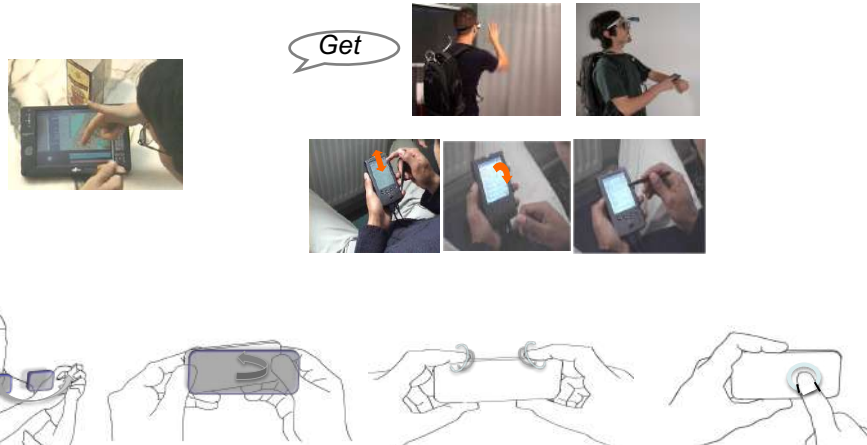
Assignment

- 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
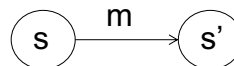
- Assignment (s, m, s')
  $\Leftrightarrow$
  Reach (s, m, s')
  $\wedge\ (\forall\ m' \in M.\ Reach(s, m',s') \Rightarrow m'=m)$

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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

Speech

s → s'
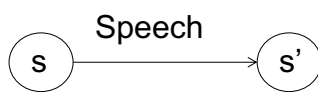
https://store.google.com/uk/product/google_home

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)
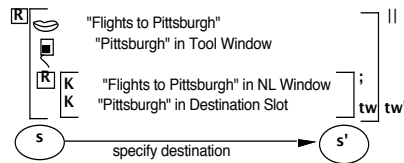
Complementarity

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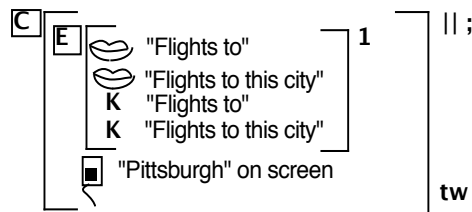
Redundancy

- 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.

Redundancy

Mark

https://www.cybertek.fr/peripherique-de-jeu/thrustmaster/33079.aspx

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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

Combination aspects		Schema 1	Schema 2	Schema 3	Schema 4	Schema 5
	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

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

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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puzzle on screen

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Multimodality:
Combination of modalities

- Puzzle

M2 = <screen, color>

M3 = <mini-screen, crosses>

Multimodality:
Combination of modalities

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

Combination schemas

Combination aspects		Anachronism	Sequence	Concomitance	Coincidence	Parallelism
	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

Combination aspects		Anachronism	Sequence	Concomitance	Coincidence	Parallelism
	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)

CARE combination

Complementarity 2

Complementarity 1 — Redundancy / Equivalence

Languages

| 3D orientation (radians) | 3d location | Mouse Notes commands | Speech Notes commands |

Devices

| Magnetometer | Localization sensor | Mouse | Microphone |

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Multimodality
Combination of modalities

CARE combination

Languages

Devices

Task: Mark a position on ground

Complementarity 2

Complementarity 1 — Redundancy / Equivalence

Location and Orientation of the pilot | Location and Orientation of the plane | HOTAS commands | Speech commands

Devices: Location and Orientation of the pilot | Devices: Location and Orientation of the plane | HOTAS | Microphone

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Multimodality
Combination of modalities

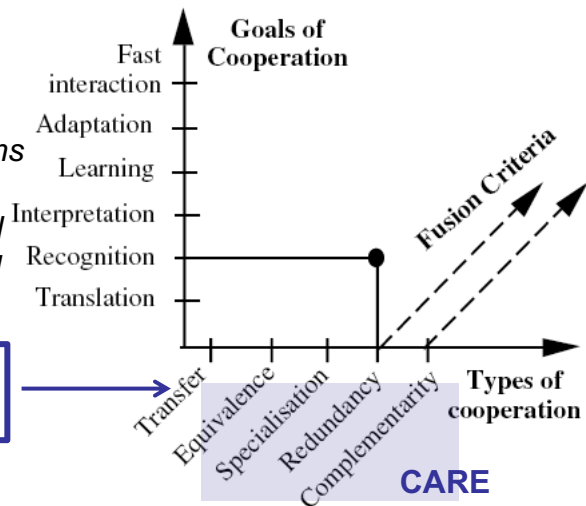- CARE properties
- TYCOON design space

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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
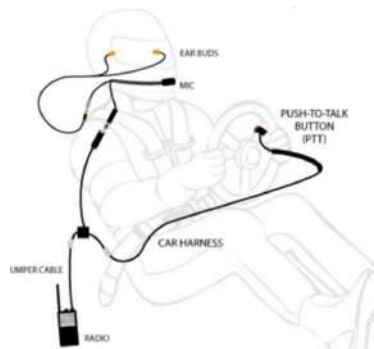
TRANSFER →

Goals of Cooperation

Fast interaction
Adaptation
Learning
Interpretation
Recognition
Translation

Fusion Criteria

Transfer
Equivalence
Specialisation
Redundancy
Complementarity

Types of cooperation

CARE

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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)*

EAR BUDS
MIC
PUSH-TO-TALK BUTTON (PTT)
CAR HARNESS
JUMPER CABLE
RADIO

https://www.sampsonracing.com/2-Way-Hole-Mount-PTT-with-Mounting-Bracket-p/p0520.htm
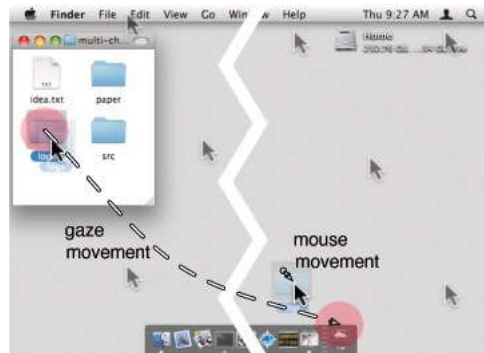
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Multimodality
Transfer of modalities

- 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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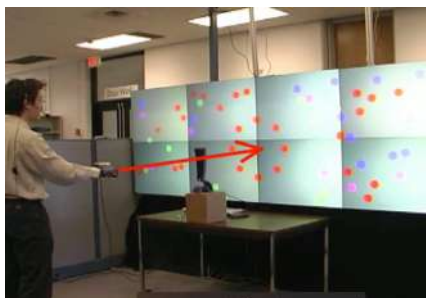# Multimodality
Transfer of modalities

- 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

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

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
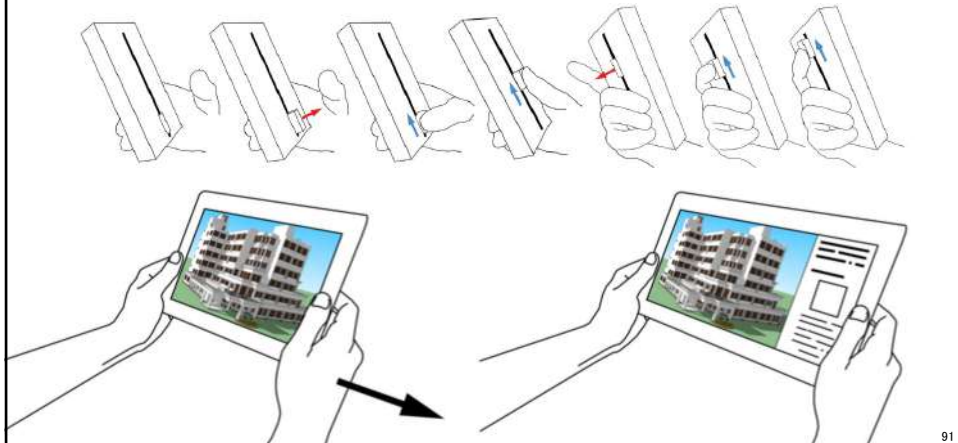 - Experimental study

One research avenue: reconfigurable device

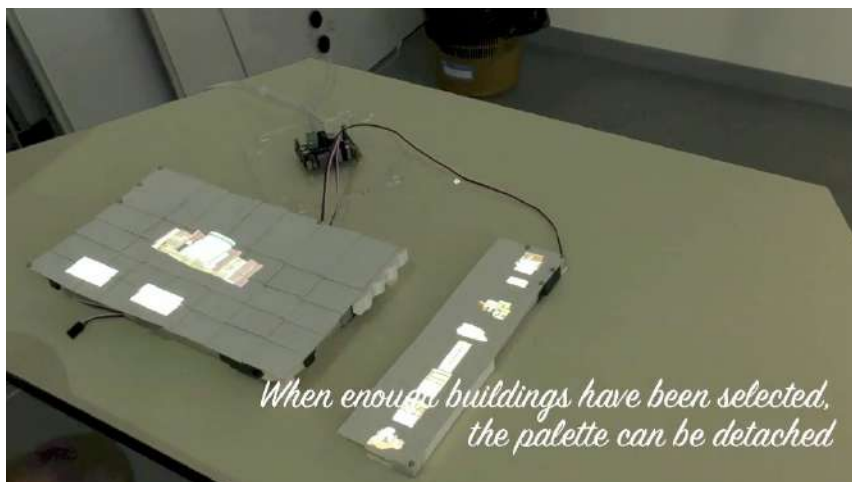*Laurence Nigay – laurence.nigay@univ-grenoble-alpes.fr*
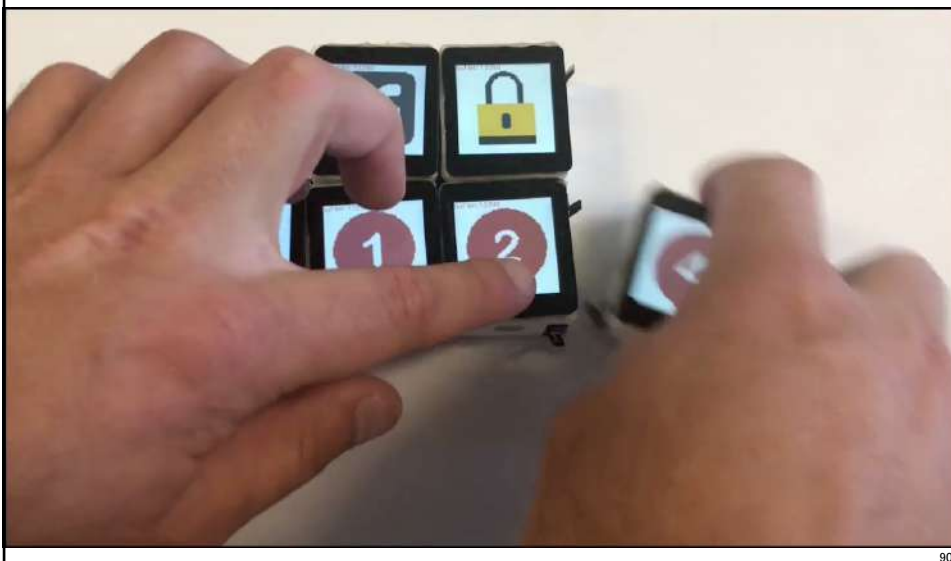
One research avenue: shape-changing UI

- Modality <device, language> with a deformable device

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One research avenue: shape-changing UI

When enough buildings have been selected, the palette can be detached

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Readings

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- Bouchet, J., Nigay, L., Ganille, T. ICARE Software Components for Rapidly Developing Multimodal Interfaces. Proceedings of ICMI'04, ACM Press, pp. 251-258
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- 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
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- Vernier, F,. Nigay, L. A Framework for the Combination and Characterization of Output Modalities, Proceedings of DSV-IS2000, Springer-Verlag, pp. 32-48
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