Multimodal Interaction

Lesson 9 Multimodal Coordination

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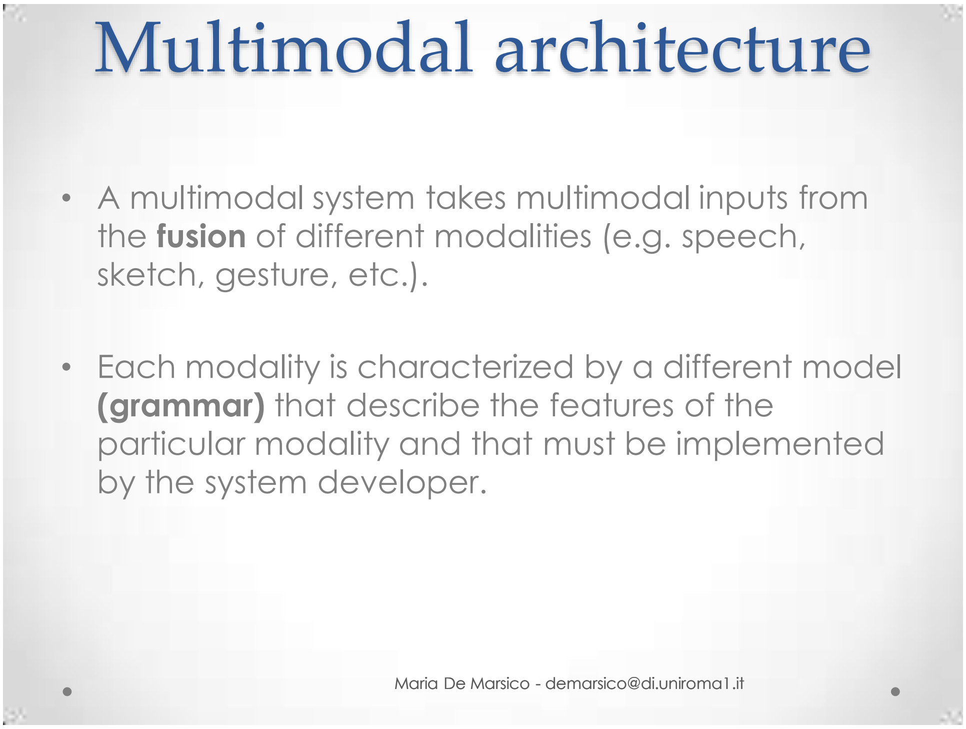
Credits

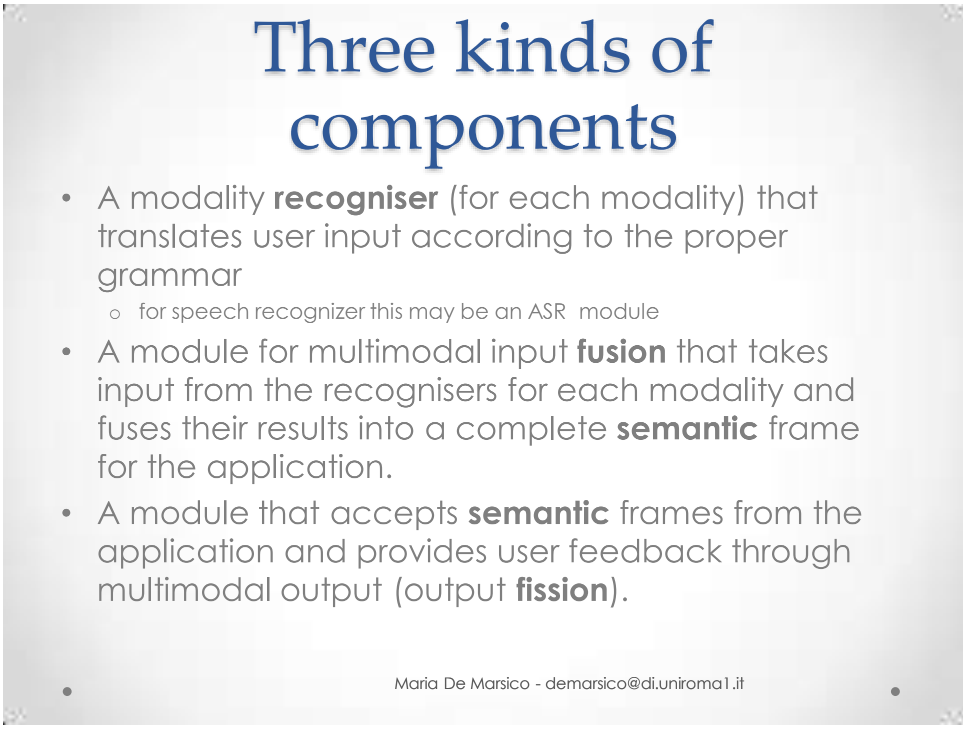
Derived from:

- Patrizia Grifoni. **Multimodal Human Computer Interaction and Pervasive Services**. Information Science Reference. 2009
- Niels Ole Bernsen,_Laila Dybkjr. **Multimodal Usability**. Springer 2009
- Hank Liao. **Multimodal Fusion**. http://mi.eng.cam.ac.uk/~hl251/Pubs/liao02mphil.pdf



Multimodal architecture

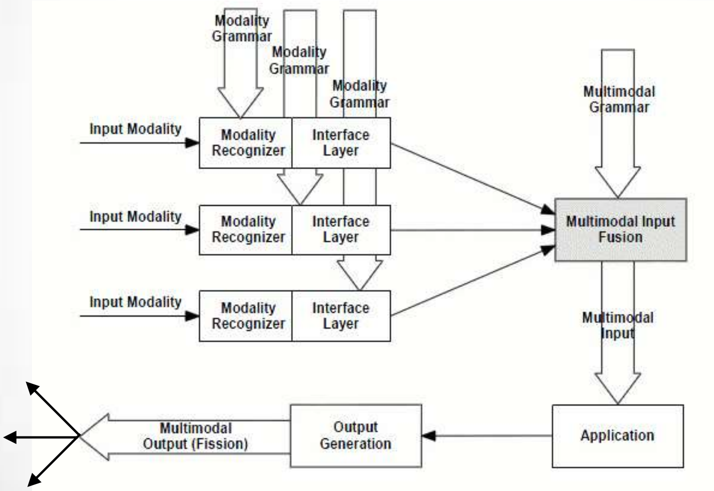
- A multimodal system takes multimodal inputs from the **fusion** of different modalities (e.g. speech, sketch, gesture, etc.).
- Each modality is characterized by a different model **(grammar)** that describe the features of the particular modality and that must be implemented by the system developer.



Three kinds of components

- A modality **recogniser** (for each modality) that translates user input according to the proper grammar
  - for speech recognizer this may be an ASR module
- A module for multimodal input **fusion** that takes input from the recognisers for each modality and fuses their results into a complete **semantic** frame for the application.
- A module that accepts **semantic** frames from the application and provides user feedback through multimodal output (output **fission**).

Multimodal Architecture Scheme



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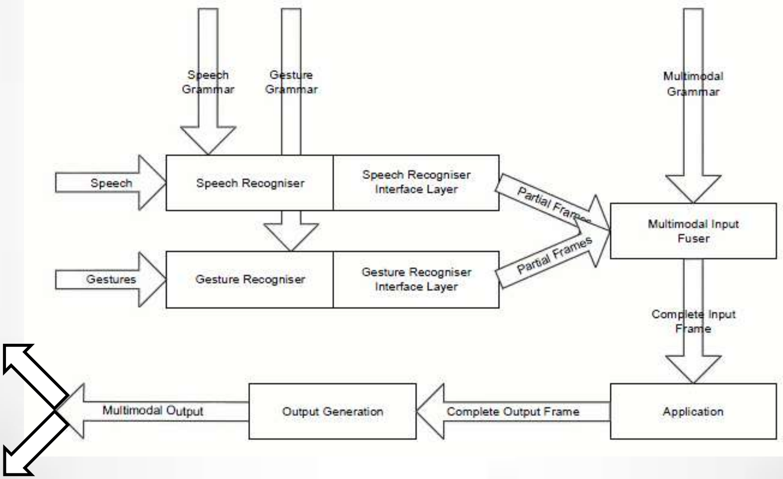
Multimodal Architecture Scheme: example



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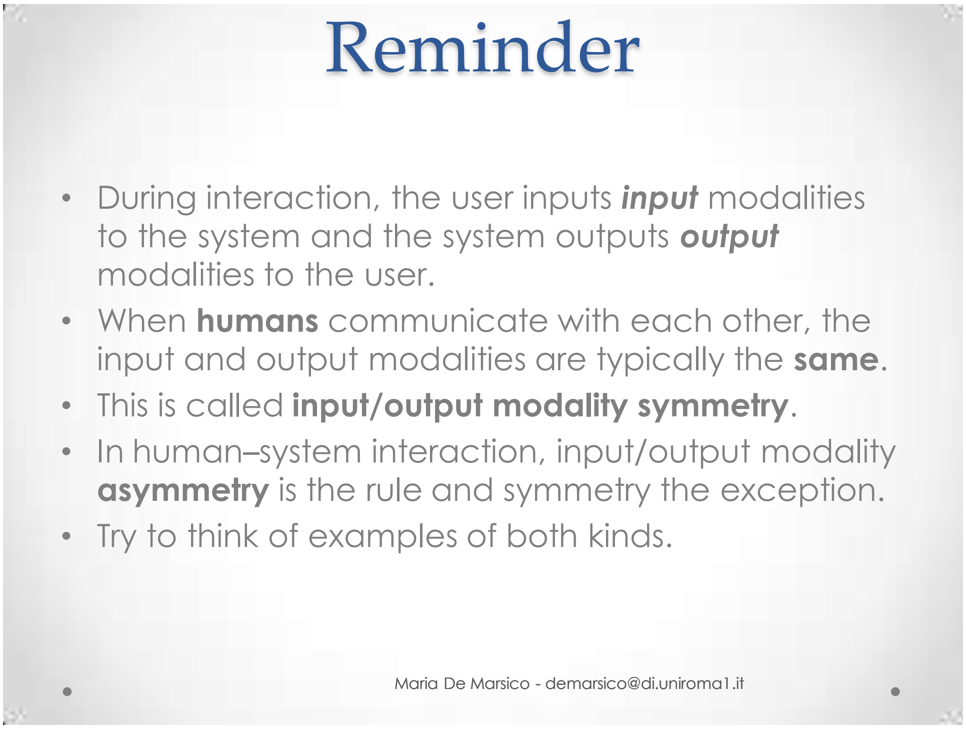

Reminder

- During interaction, the user inputs ***input*** modalities to the system and the system outputs ***output*** modalities to the user.
- When **humans** communicate with each other, the input and output modalities are typically the **same**.
- This is called **input/output modality symmetry**.
- In human–system interaction, input/output modality **asymmetry** is the rule and symmetry the exception.
- Try to think of examples of both kinds.

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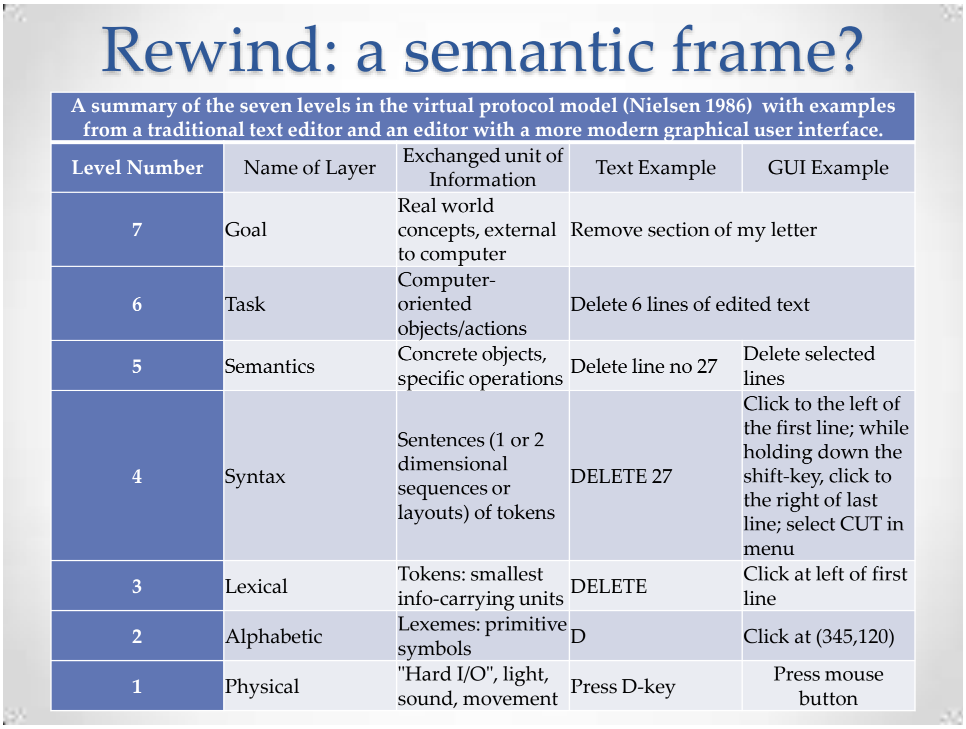
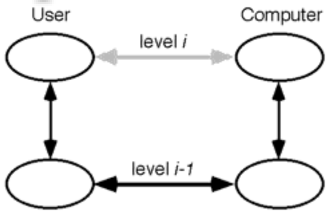


Rewind: a semantic frame?

A summary of the seven levels in the virtual protocol model (Nielsen 1986) with examples from a traditional text editor and an editor with a more modern graphical user interface.

Level Number	Name of Layer	Exchanged unit of Information	Text Example	GUI Example
7	Goal	Real world concepts, external to computer	Remove section of my letter	
6	Task	Computer-oriented objects/actions	Delete 6 lines of edited text	
5	Semantics	Concrete objects, specific operations	Delete line no 27	Delete selected lines
4	Syntax	Sentences (1 or 2 dimensional sequences or layouts) of tokens	DELETE 27	Click to the left of the first line; while holding down the shift-key, click to the right of last line; select CUT in menu
3	Lexical	Tokens: smallest info-carrying units	DELETE	Click at left of first line
2	Alphabetic	Lexemes: primitive symbols	D	Click at (345,120)
1	Physical	"Hard I/O", light, sound, movement	Press D-key	Press mouse button

Back to Nielsen's virtual protocol model



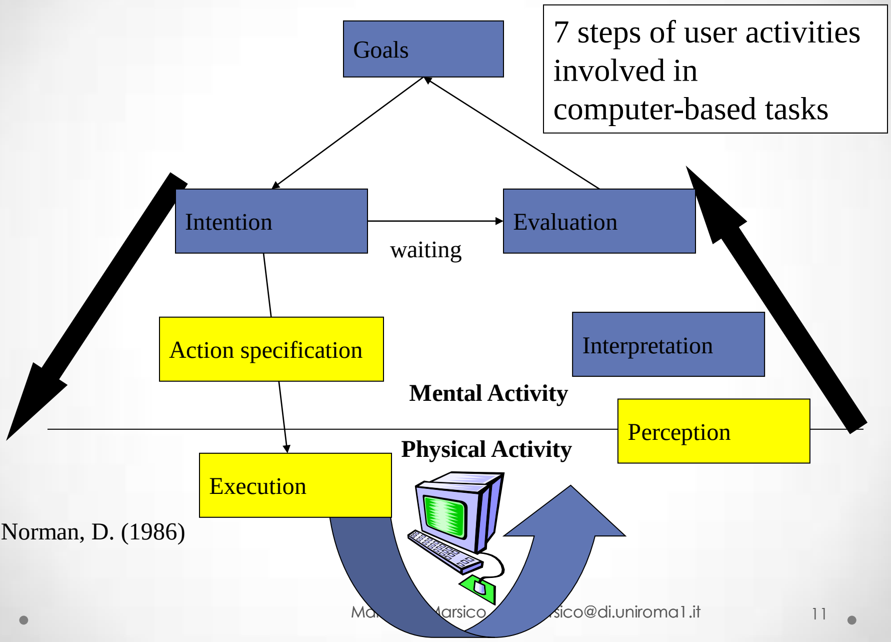
The communication principle in the layered protocol model. A communication on level *i* of the model (indicated by the gray arrow) is realized by an exchange of information on level *i-1*.
Both the user and the computer will have to translate between the two levels as indicated by the vertical arrows.
The units of information exchanged at each level of the model are listed in the Table backwards

Does this remind you something?

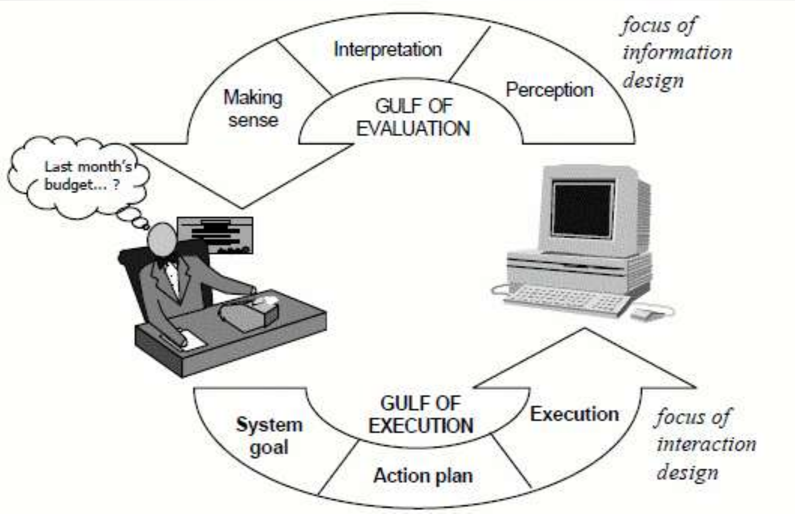
From a conceptual point of view… 7 is a magic number!

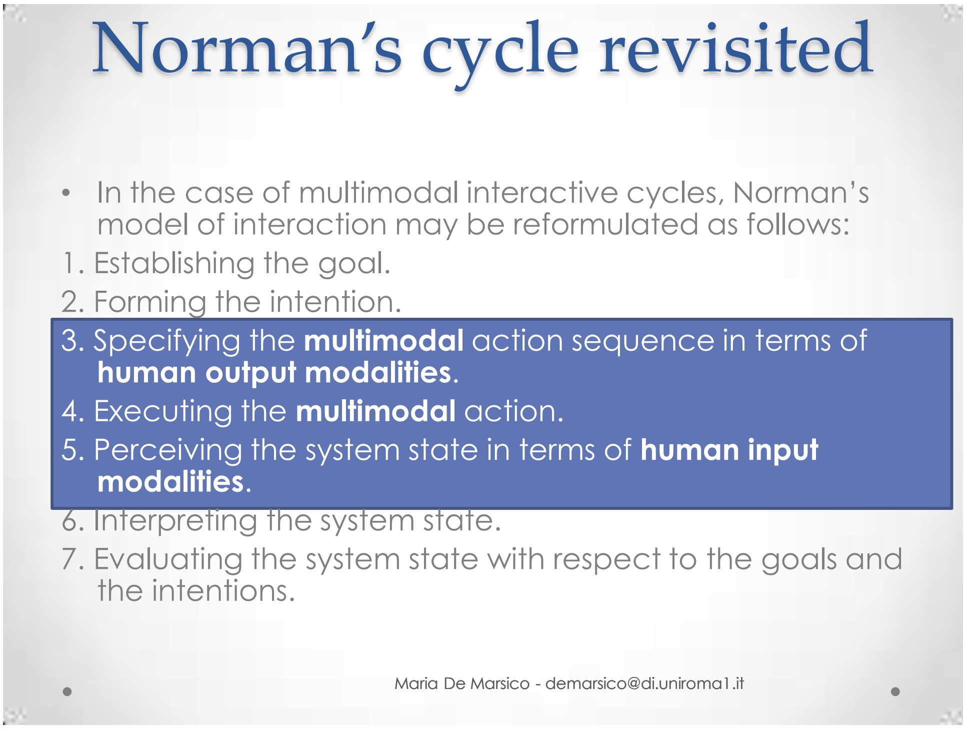
- Let us further remind the rivisitation of Norman's cycle, especially for what concerns its central items

7 steps of user activities involved in computer-based tasks



[1]Norman, D. (1986)

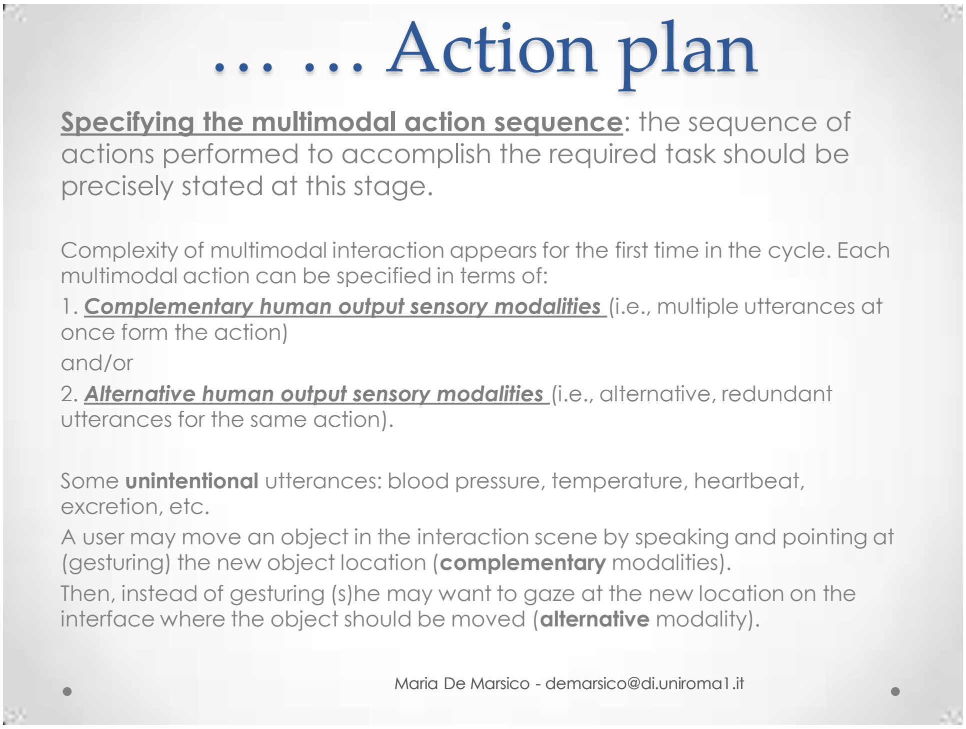




Norman’s cycle revisited

- In the case of multimodal interactive cycles, Norman’s model of interaction may be reformulated as follows:

1. Establishing the goal.
2. Forming the intention.
3. Specifying the **multimodal** action sequence in terms of **human output modalities**.
4. Executing the **multimodal** action.
5. Perceiving the system state in terms of **human input modalities**.
6. Interpreting the system state.
7. Evaluating the system state with respect to the goals and the intentions.



… … Action plan

Specifying the multimodal action sequence: the sequence of actions performed to accomplish the required task should be precisely stated at this stage.

Complexity of multimodal interaction appears for the first time in the cycle. Each multimodal action can be specified in terms of:

1. ***Complementary human output sensory modalities*** (i.e., multiple utterances at once form the action)

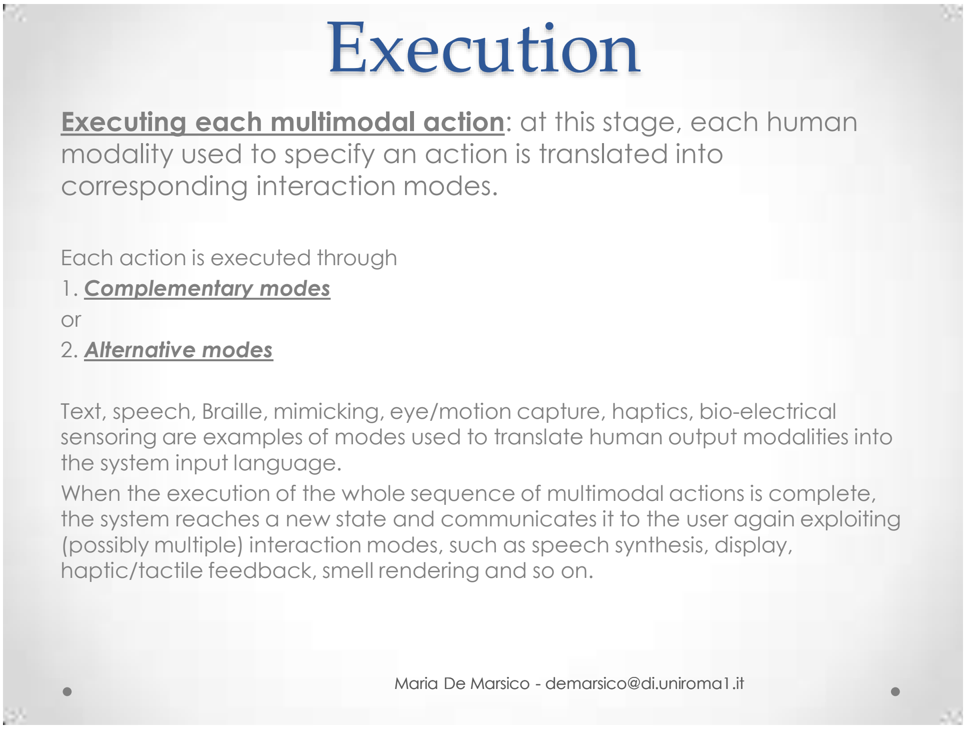
and/or

2. ***Alternative human output sensory modalities*** (i.e., alternative, redundant utterances for the same action).

Some **unintentional** utterances: blood pressure, temperature, heartbeat, excretion, etc.

A user may move an object in the interaction scene by speaking and pointing at (gesturing) the new object location (**complementary** modalities).

Then, instead of gesturing (s)he may want to gaze at the new location on the interface where the object should be moved (**alternative** modality).



Execution

Executing each multimodal action: at this stage, each human modality used to specify an action is translated into corresponding interaction modes.

Each action is executed through

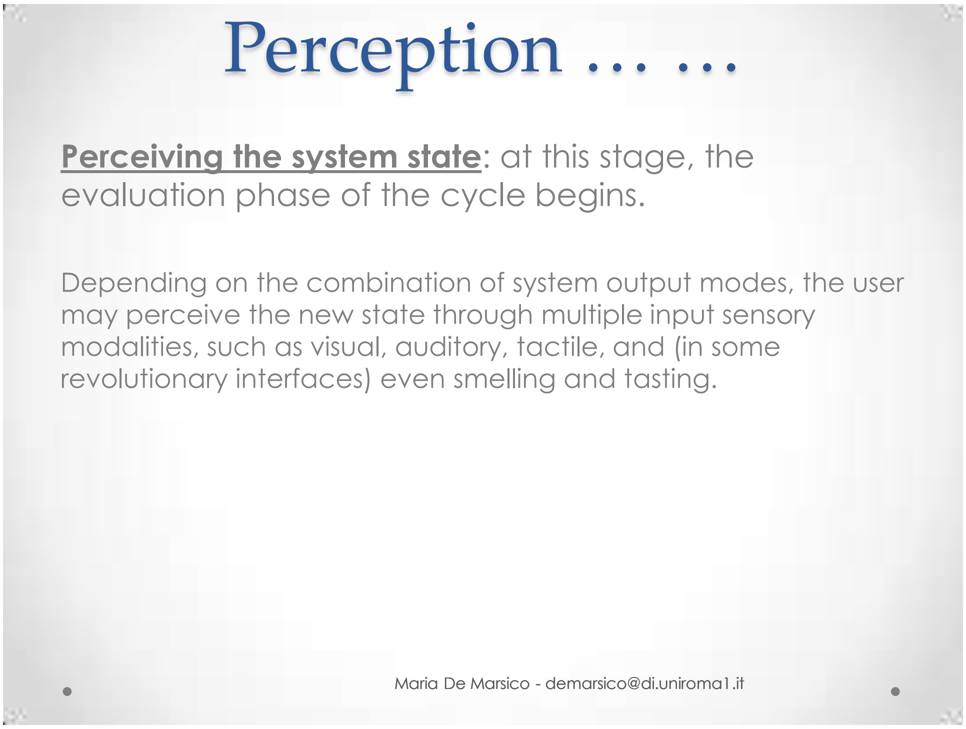
1. ***Complementary modes***

or

2. ***Alternative modes***

Text, speech, Braille, mimicking, eye/motion capture, haptics, bio-electrical sensoring are examples of modes used to translate human output modalities into the system input language.

When the execution of the whole sequence of multimodal actions is complete, the system reaches a new state and communicates it to the user again exploiting (possibly multiple) interaction modes, such as speech synthesis, display, haptic/tactile feedback, smell rendering and so on.



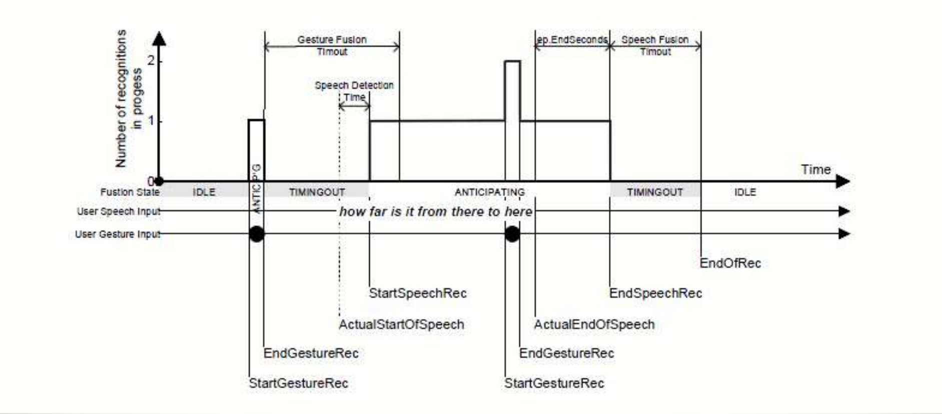
Perception … …

Perceiving the system state: at this stage, the evaluation phase of the cycle begins.

Depending on the combination of system output modes, the user may perceive the new state through multiple input sensory modalities, such as visual, auditory, tactile, and (in some revolutionary interfaces) even smelling and tasting.

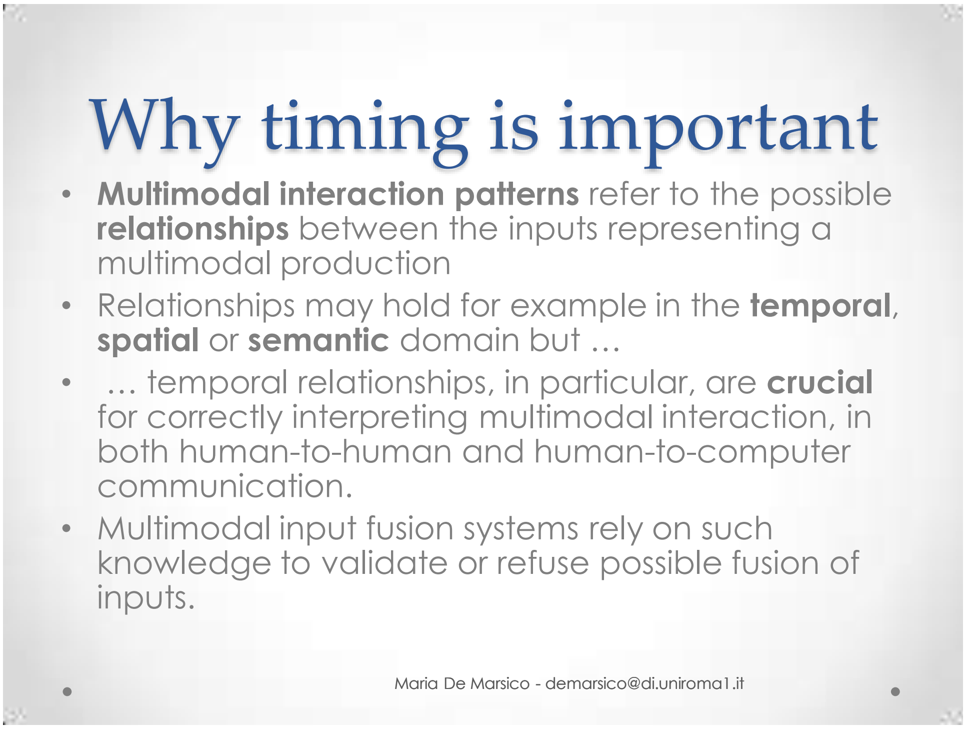
An example of timing

(from the system described in Hank Liao. **Multimodal Fusion)**



An example of timing

- Tthe algorithm to captures multimodal inputs and increments a counter for every recognition process that is started, and decrement s it every time one reports ending.
- When the counter is decremented to zero, a timer is started depending whether the end recognition message came from the gesture recogniser or speech. This is necessary because the speech recogniser also has an ep.EndSeconds length to ensure the proper detection of the end of speech, whereas the gesture recogniser lacks this delay.
- The ep.EndSeconds parameter is set at 2.0 seconds, the FUSION_TIMEOUT_SPEECH timeout interval at 1000 milliseconds, whereas the FUSION_TIMEOUT_GESTURE is set at 2000 milliseconds; this was found to work adequately but could be tuned to decrease latency.
- The Windows timer ID_FUSIONTIMEOUT is set at the timeout interval for the modality. When it times out, as indicated by the EndOfRec in Figure, the FusionCallback function is called which performs the final fusion routines, checks for complete frames, finds the best complete command frame, and whether to accept and send this frame to the application or to send a rejection.
- If while the timer is timing out another start recognition event is received, the timer is reset.



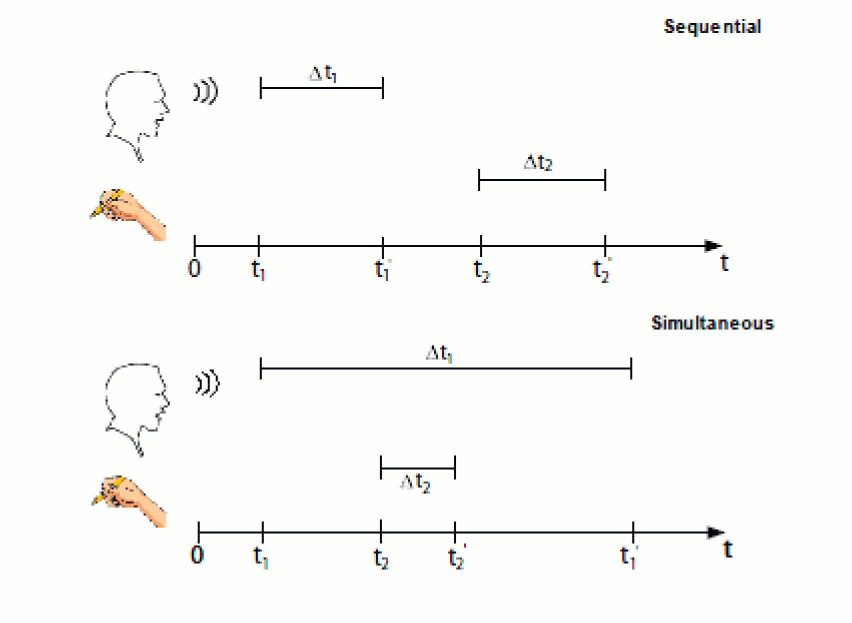
Why timing is important

- **Multimodal interaction patterns** refer to the possible **relationships** between the inputs representing a multimodal production
- Relationships may hold for example in the **temporal**, **spatial** or **semantic** domain but …
- … temporal relationships, in particular, are **crucial** for correctly interpreting multimodal interaction, in both human-to-human and human-to-computer communication.
- Multimodal input fusion systems rely on such knowledge to validate or refuse possible fusion of inputs.

Why timing is important

- The **qualitative** and **quantitative** aspects of the temporal relationships have been analyzed in several researches in order to provide a better design of multimodal input fusion modules, but …
- … also to progress the fundamental understanding of human communication.

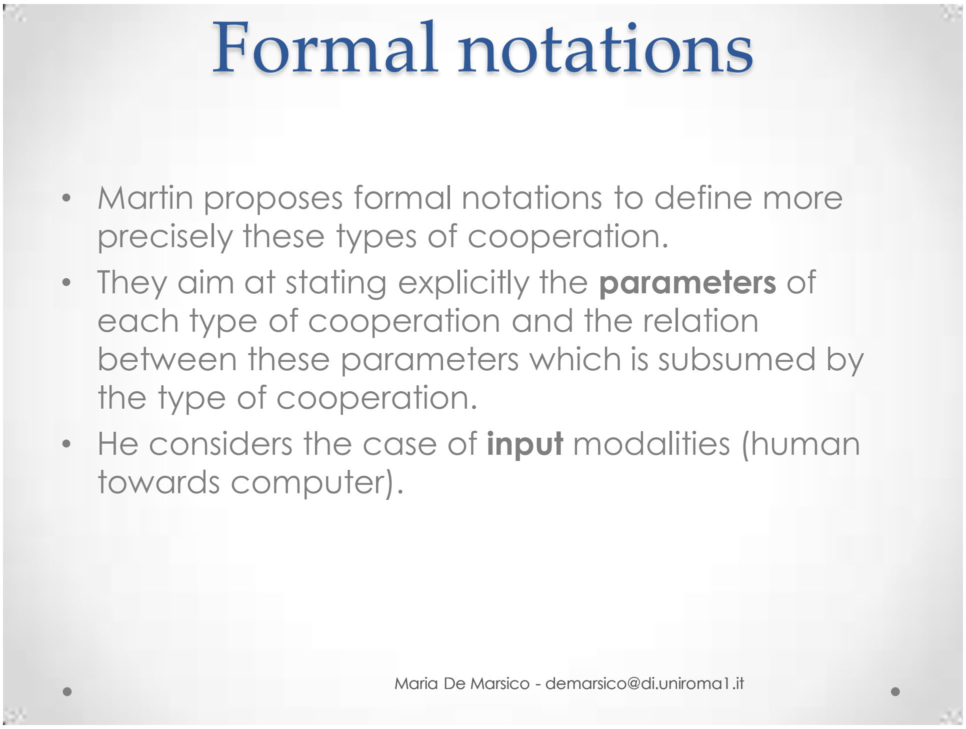
Reminder: time relations



More timing relations

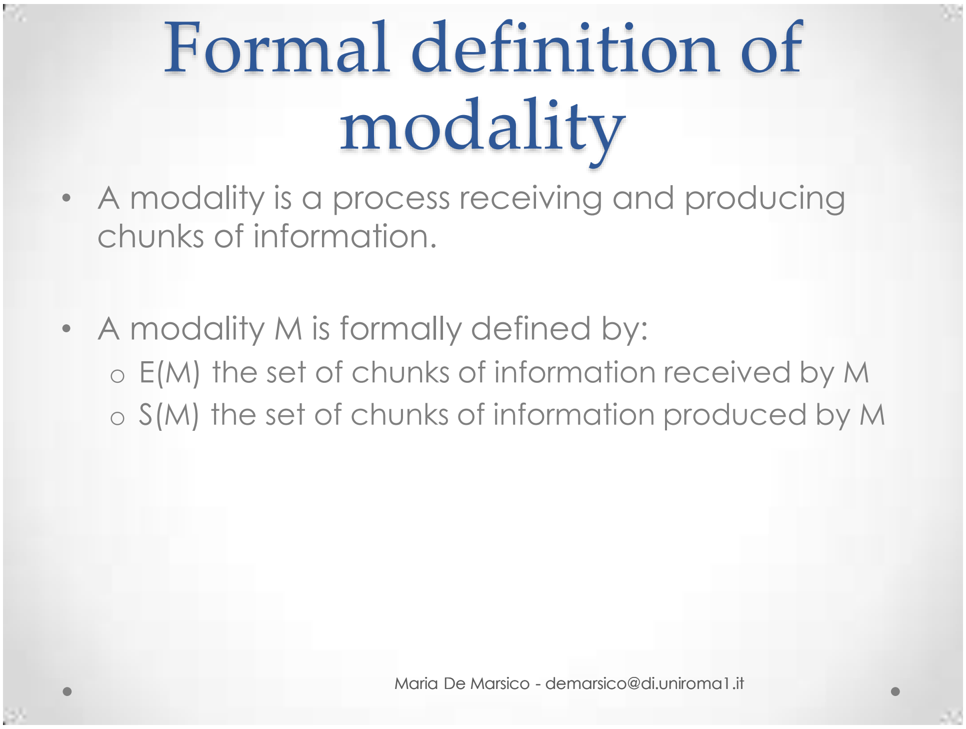
- Both overlapping and non-overlapping interactions can also be divided in other six types of cooperation between modalities
- Complementarity
- Concurrency,
- Equivalence
- Redundancy
- Specialization
- Transfer

(Martin, 1997)



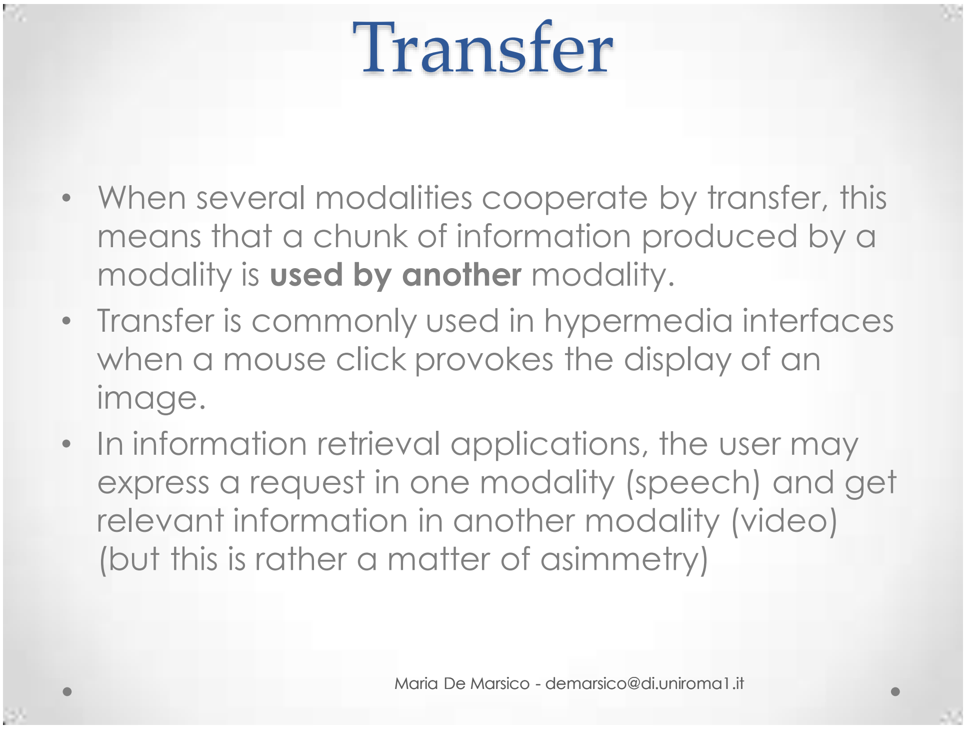
Formal notations

- Martin proposes formal notations to define more precisely these types of cooperation.
- They aim at stating explicitly the **parameters** of each type of cooperation and the relation between these parameters which is subsumed by the type of cooperation.
- He considers the case of **input** modalities (human towards computer).



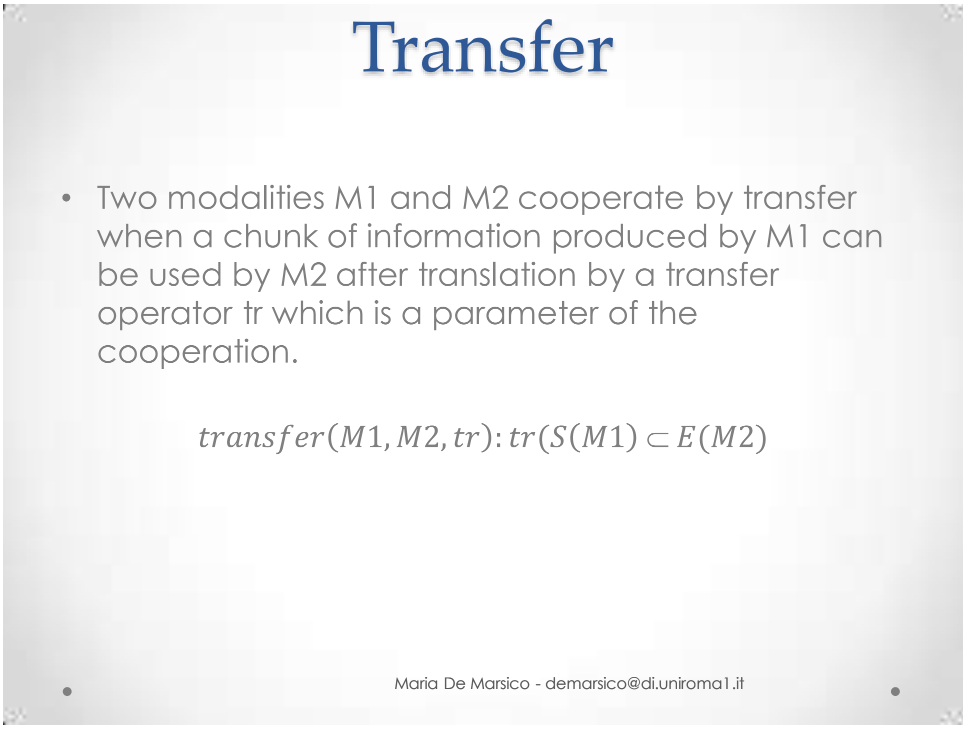
Formal definition of modality

- A modality is a process receiving and producing chunks of information.
- A modality M is formally defined by:
  - E(M) the set of chunks of information received by M
  - S(M) the set of chunks of information produced by M



Transfer

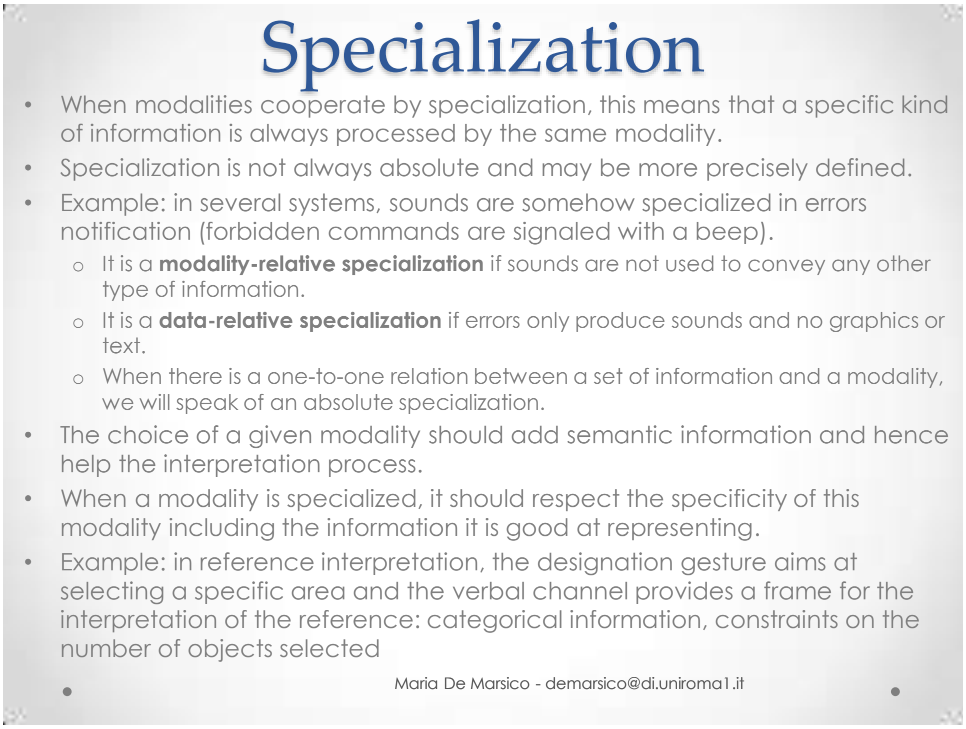
- When several modalities cooperate by transfer, this means that a chunk of information produced by a modality is **used by another** modality.
- Transfer is commonly used in hypermedia interfaces when a mouse click provokes the display of an image.
- In information retrieval applications, the user may express a request in one modality (speech) and get relevant information in another modality (video) (but this is rather a matter of asimmetry)



Transfer

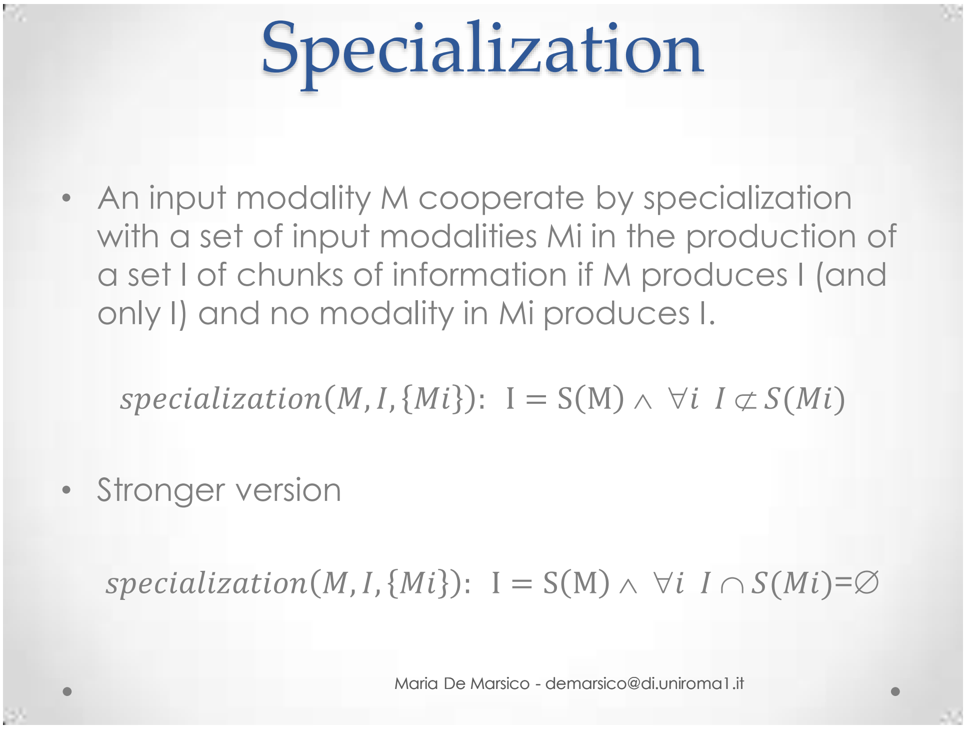
- Two modalities M1 and M2 cooperate by transfer when a chunk of information produced by M1 can be used by M2 after translation by a transfer operator tr which is a parameter of the cooperation.

$$transfer(M1, M2, tr): tr(S(M1) \subset E(M2)$$



Specialization

- When modalities cooperate by specialization, this means that a specific kind of information is always processed by the same modality.
- Specialization is not always absolute and may be more precisely defined.
- Example: in several systems, sounds are somehow specialized in errors notification (forbidden commands are signaled with a beep).
    - It is a **modality-relative specialization** if sounds are not used to convey any other type of information.
    - It is a **data-relative specialization** if errors only produce sounds and no graphics or text.
    - When there is a one-to-one relation between a set of information and a modality, we will speak of an absolute specialization.
- The choice of a given modality should add semantic information and hence help the interpretation process.
- When a modality is specialized, it should respect the specificity of this modality including the information it is good at representing.
- Example: in reference interpretation, the designation gesture aims at selecting a specific area and the verbal channel provides a frame for the interpretation of the reference: categorical information, constraints on the number of objects selected



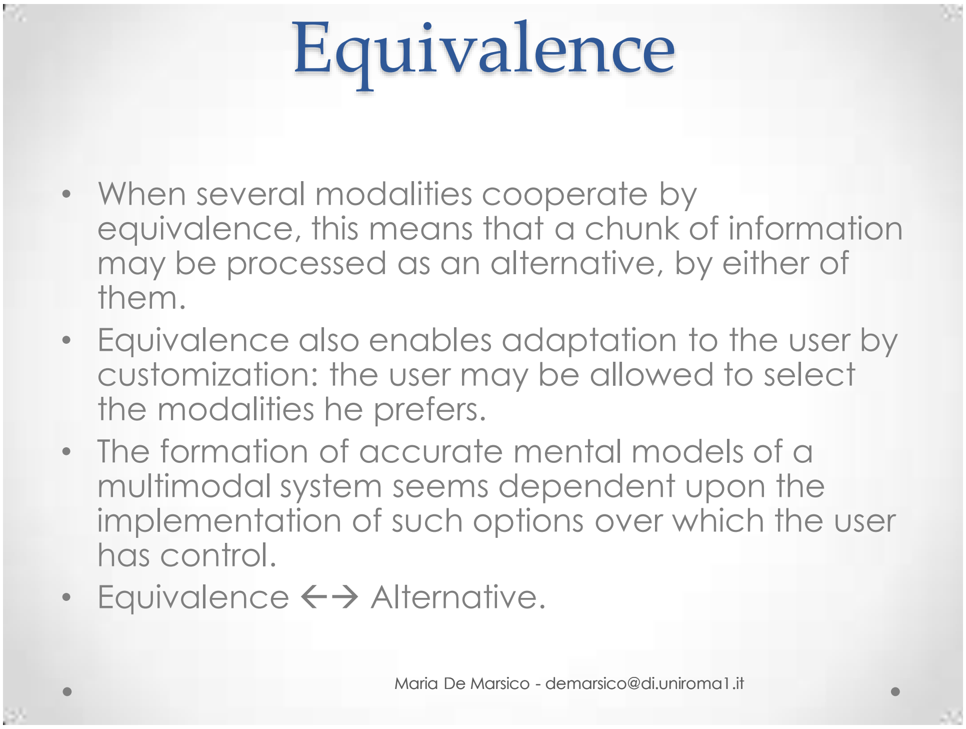
Specialization

- An input modality M cooperate by specialization with a set of input modalities Mi in the production of a set I of chunks of information if M produces I (and only I) and no modality in Mi produces I.

$$specialization(M,I,\{Mi\}):\ \mathrm{I} = \mathrm{S(M)} \wedge \ \forall i\ \ I \not\subset S(Mi)$$

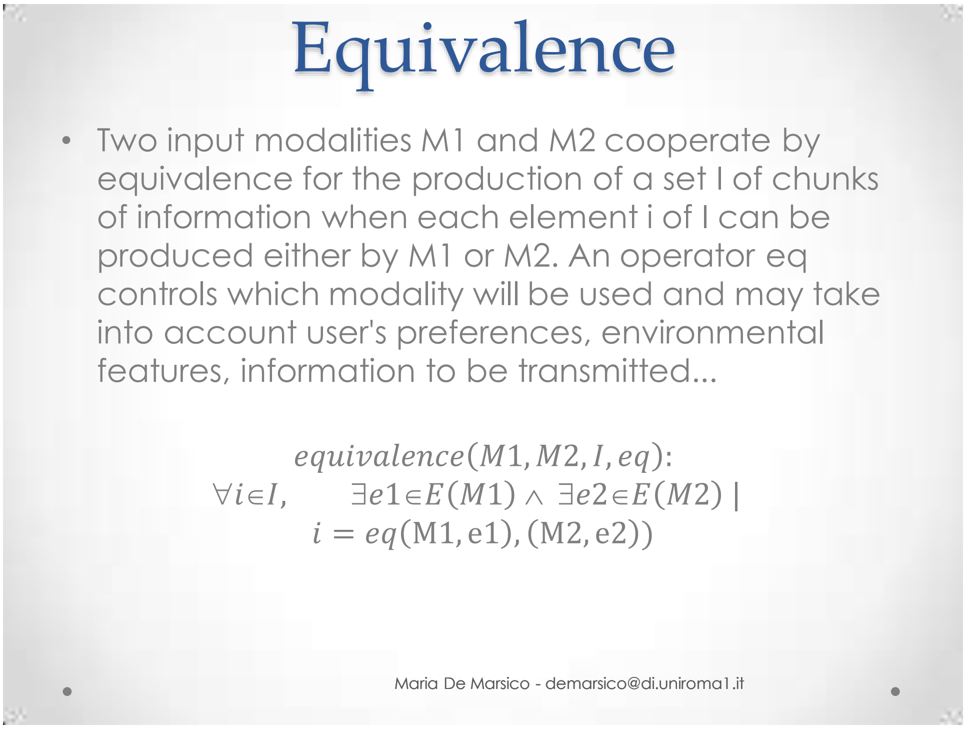
- Stronger version

$$specialization(M,I,\{Mi\}):\ \mathrm{I} = \mathrm{S(M)} \wedge \ \forall i\ \ I \cap S(Mi) = \emptyset$$



Equivalence

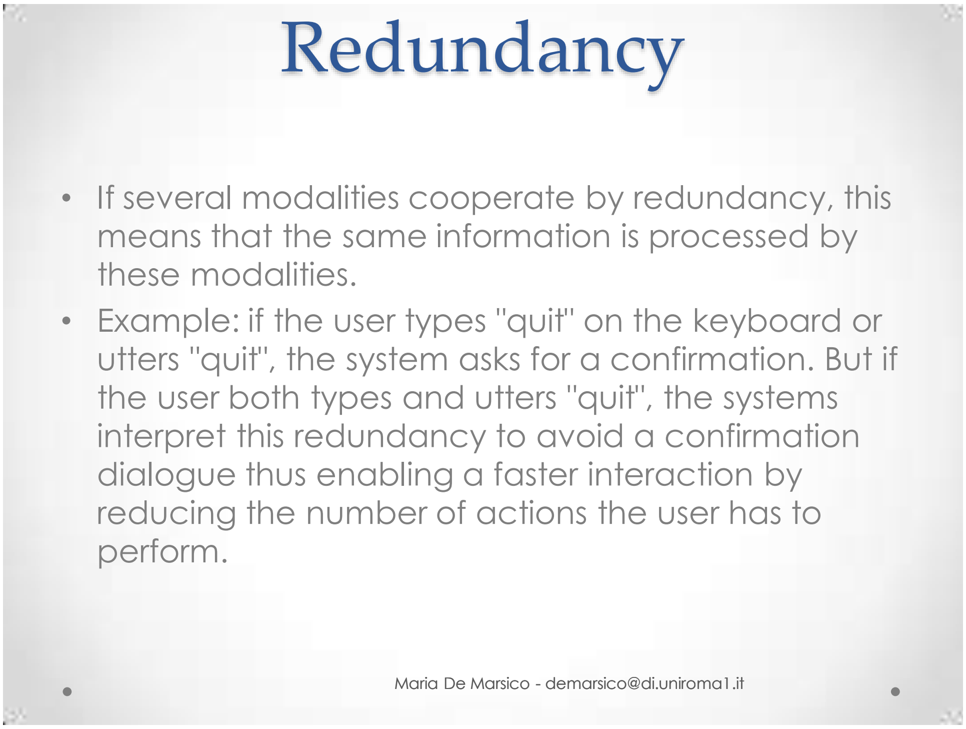
- When several modalities cooperate by equivalence, this means that a chunk of information may be processed as an alternative, by either of them.
- Equivalence also enables adaptation to the user by customization: the user may be allowed to select the modalities he prefers.
- The formation of accurate mental models of a multimodal system seems dependent upon the implementation of such options over which the user has control.
- Equivalence <-> Alternative.



Equivalence

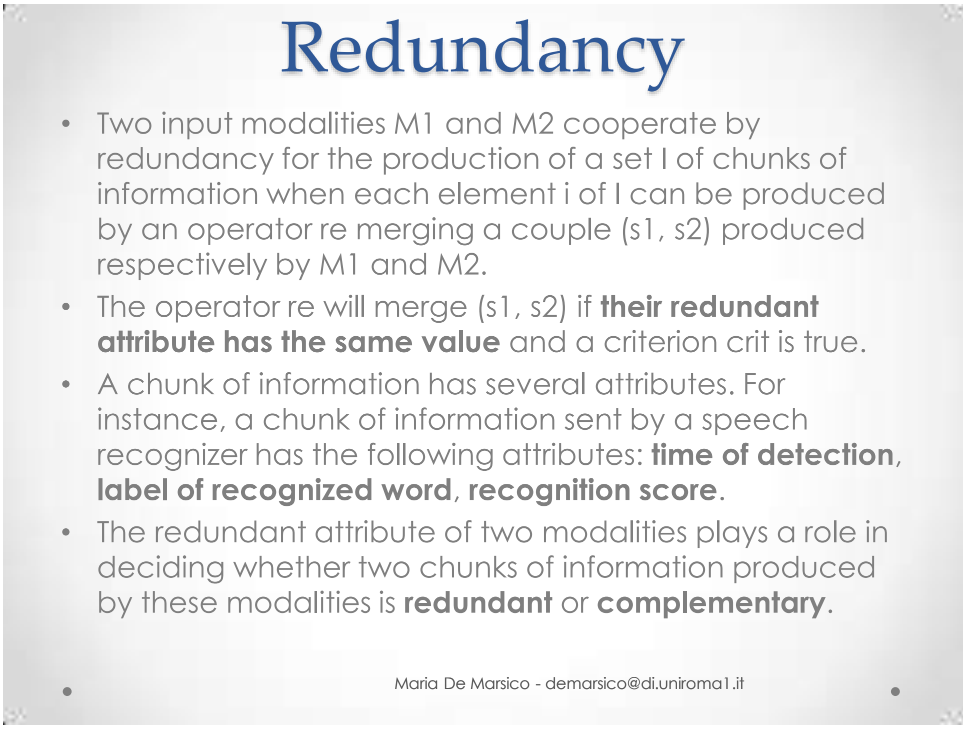
- Two input modalities M1 and M2 cooperate by equivalence for the production of a set I of chunks of information when each element i of I can be produced either by M1 or M2. An operator eq controls which modality will be used and may take into account user's preferences, environmental features, information to be transmitted...

$$
\begin{gathered}
equivalence(M1, M2, I, eq): \\
\forall i \in I, \qquad \exists e1 \in E(M1) \wedge \exists e2 \in E(M2) \mid \\
i = eq(\mathrm{M1}, \mathrm{e1}), (\mathrm{M2}, \mathrm{e2}))
\end{gathered}
$$



Redundancy

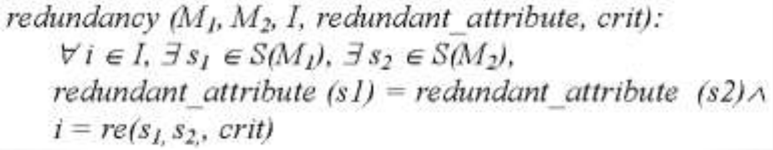
- If several modalities cooperate by redundancy, this means that the same information is processed by these modalities.
- Example: if the user types "quit" on the keyboard or utters "quit", the system asks for a confirmation. But if the user both types and utters "quit", the systems interpret this redundancy to avoid a confirmation dialogue thus enabling a faster interaction by reducing the number of actions the user has to perform.



Redundancy

- Two input modalities M1 and M2 cooperate by redundancy for the production of a set I of chunks of information when each element i of I can be produced by an operator re merging a couple (s1, s2) produced respectively by M1 and M2.
- The operator re will merge (s1, s2) if **their redundant attribute has the same value** and a criterion crit is true.
- A chunk of information has several attributes. For instance, a chunk of information sent by a speech recognizer has the following attributes: **time of detection**, **label of recognized word**, **recognition score**.
- The redundant attribute of two modalities plays a role in deciding whether two chunks of information produced by these modalities is **redundant** or **complementary**.

Redundancy



$$
\begin{aligned}
&\textit{redundancy}\ (M_1, M_2, I, \textit{redundant\_attribute}, \textit{crit}):\\
&\quad \forall i \in I, \exists s_1 \in S(M_1), \exists s_2 \in S(M_2),\\
&\quad \textit{redundant\_attribute}\ (s1) = \textit{redundant\_attribute}\ \ (s2) \wedge\\
&\quad i = re(s_1, s_2, \textit{crit})
\end{aligned}
$$

Complementarity

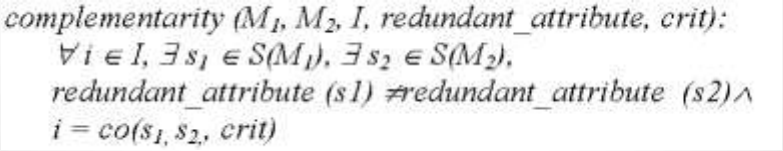
- When several modalities cooperate by complementarity, it means that different chunks of information are processed by each modality but have to be **merged**.
- First systems enabled the "put that there" command for the manipulation of graphical objects.
- Example: if the user wants to create a radio button, he may type its name on the keyboard and select its position with the mouse. → These two chunks of information have to be merged to create the button with the right name at the right position.
- Complementarity may enable a faster interaction since the modalities can be used **simultaneously** and convey shorter messages which are moreover better recognized than long messages.
- Complementarity may **also improve interpretation**, for example a graphical output is sufficient for an expert but need to be completed by a textual output for a novice.
- An important issue concerning complementarity is the criterion used to merge chunks of information in different modalities. The most classical approaches are to merge them because they are **temporally coincident**, **temporally sequential** or **spatially linked**.
- Two types of behavior may feature complementarity. In the "**sequential**" behavior, the user would by example utter "what are the campsites at" and then select a town with the tactile screen. In the "**synergistic**" behavior, the user would utter "Are there any campsites here ?" and select a town with the tactile screen while pronouncing "here". The second behavior seems more common

Some notes about complementarity

- Modalities cooperating by **complementarity** may be **specialized** in different types of information.
- In the example of a graphical editor, the name of an object may be always specified with speech while its position is specified with the mouse.
- Modalities cooperating by complementarity may be also be **equivalent** for **different types of information**. As a matter of fact, the user could also select an object with the mouse and its new position with speech ("in the upper right corner").

Complementarity

- Two input modalities M1 and M2 cooperate by complementarity for the production of a set I of chunks of information when each element i of I can be produced by an operator co merging a couple (s1, s2) produced respectively by M1 and M2.
- The process co will merge (s1, s2) if their redundant attribute does not have the same value and a criterion crit is true:

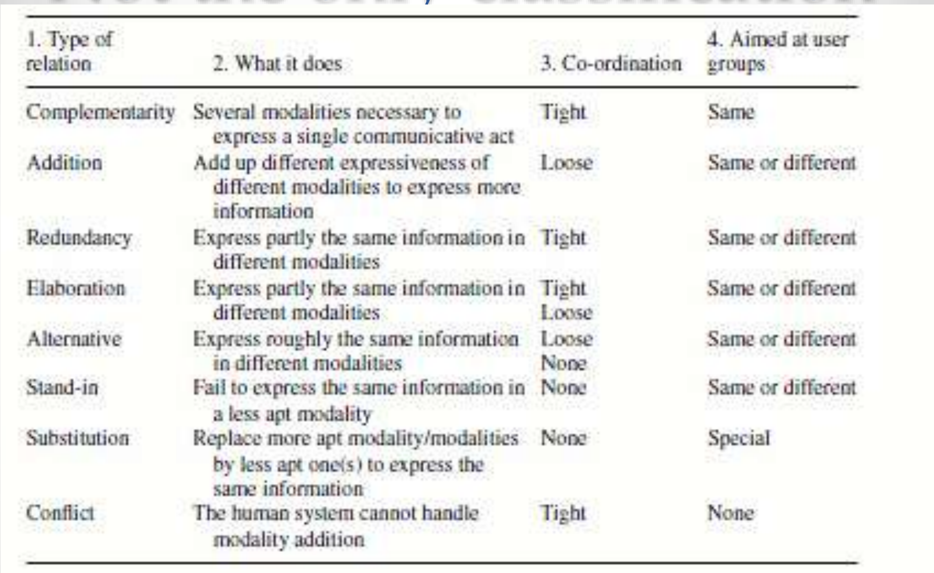


$$\begin{array}{l} complementarity\ (M_1, M_2, I, redundant\_attribute, crit): \\ \quad \forall i \in I, \exists s_1 \in S(M_1), \exists s_2 \in S(M_2), \\ \quad redundant\_attribute\ (s1) \neq redundant\_attribute\ \ (s2) \wedge \\ \quad i = co(s_1, s_2, crit) \end{array}$$

Concurrency

- when several modalities cooperate by concurrency, it means that **different** chunks of information **are processed by several modalities** at the same time but **must not be merged**.
- This may enable a faster interaction since several modalities are used in parallel.

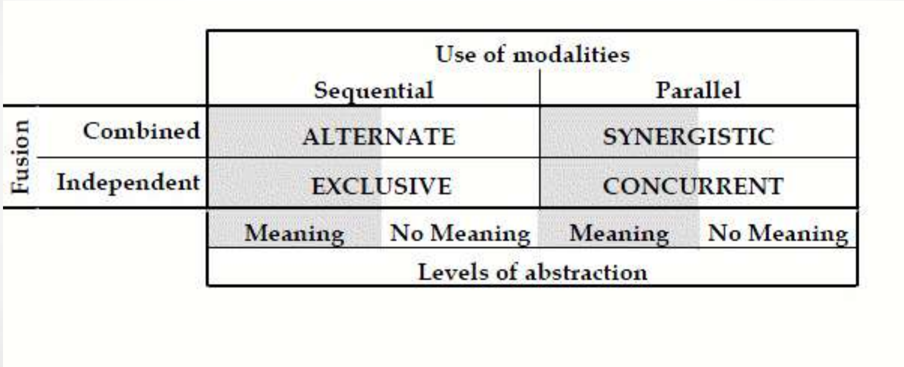
Not the only classification



1. Type of relation	2. What it does	3. Co-ordination	4. Aimed at user groups
Complementarity	Several modalities necessary to express a single communicative act	Tight	Same
Addition	Add up different expressiveness of different modalities to express more information	Loose	Same or different
Redundancy	Express partly the same information in different modalities	Tight	Same or different
Elaboration	Express partly the same information in different modalities	Tight Loose	Same or different
Alternative	Express roughly the same information in different modalities	Loose None	Same or different
Stand-in	Fail to express the same information in a less apt modality	None	Same or different
Substitution	Replace more apt modality/modalities by less apt one(s) to express the same information	None	Special
Conflict	The human system cannot handle modality addition	Tight	None

From: N. Ole Bernsen, L. Dybkjær. Multimodal Usability. Springer 2009

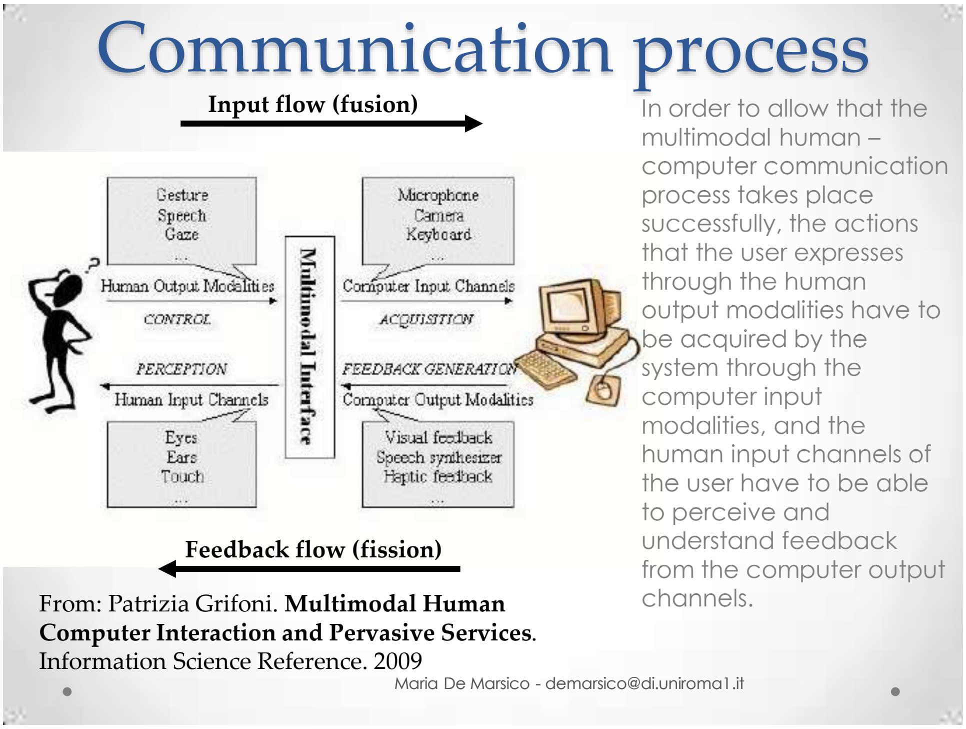
Also remind the design space



		Use of modalities			
		Sequential		Parallel	
Fusion	Combined	ALTERNATE		SYNERGISTIC	
	Independent	EXCLUSIVE		CONCURRENT	
		Meaning	No Meaning	Meaning	No Meaning
		Levels of abstraction			

Fusion and fission

- In order to enable a natural dialogue between users and computer systems, in multimodal systems the two main challenges to face are:
  - to combine and integrate information from different input modalities (**fusion** process) and
  - to generate appropriate output information (**fission** process)



Communication process

Input flow (fusion)

Feedback flow (fission)

From: Patrizia Grifoni. **Multimodal Human Computer Interaction and Pervasive Services**. Information Science Reference. 2009

In order to allow that the multimodal human – computer communication process takes place successfully, the actions that the user expresses through the human output modalities have to be acquired by the system through the computer input modalities, and the human input channels of the user have to be able to perceive and understand feedback from the computer output channels.

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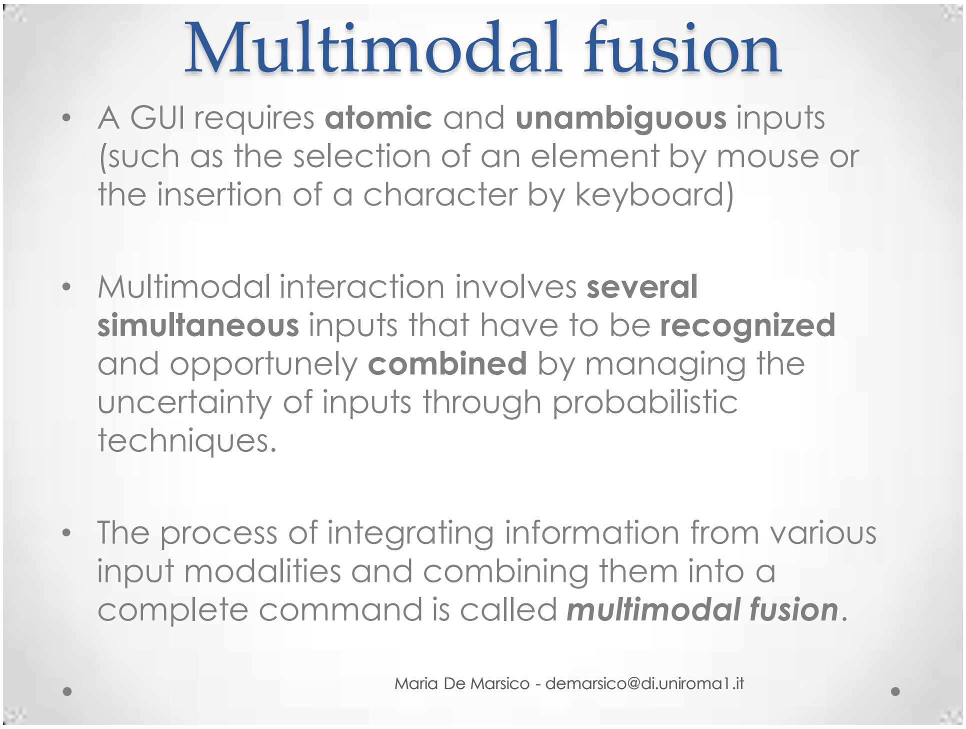

Multimodal fusion

- A GUI requires **atomic** and **unambiguous** inputs (such as the selection of an element by mouse or the insertion of a character by keyboard)
- Multimodal interaction involves **several simultaneous** inputs that have to be **recognized** and opportunely **combined** by managing the uncertainty of inputs through probabilistic techniques.
- The process of integrating information from various input modalities and combining them into a complete command is called ***multimodal fusion***.

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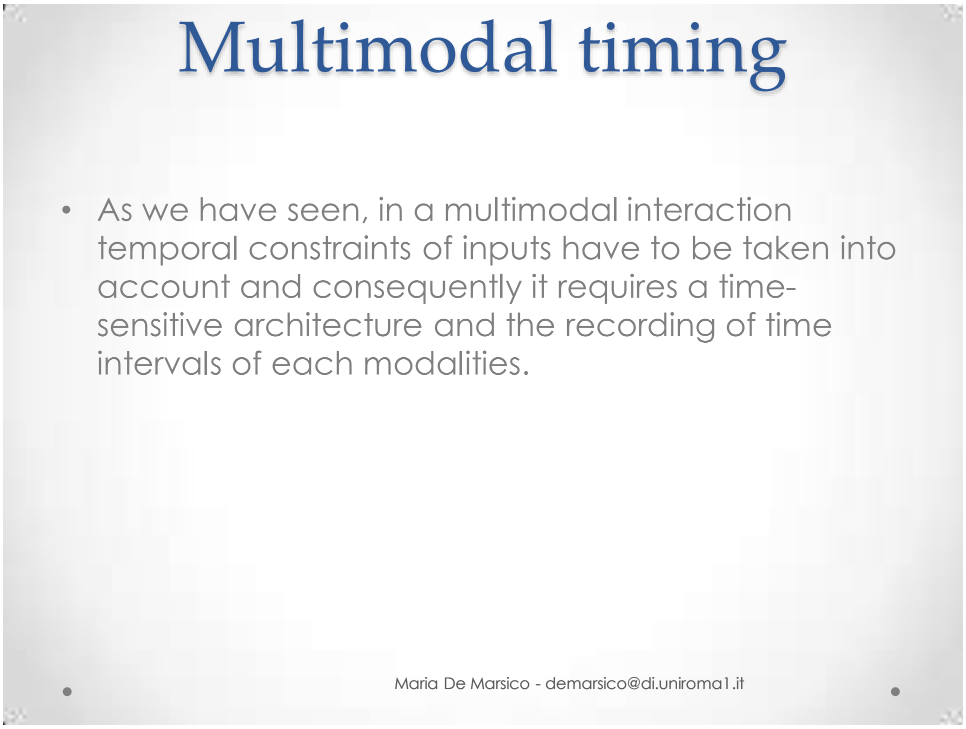
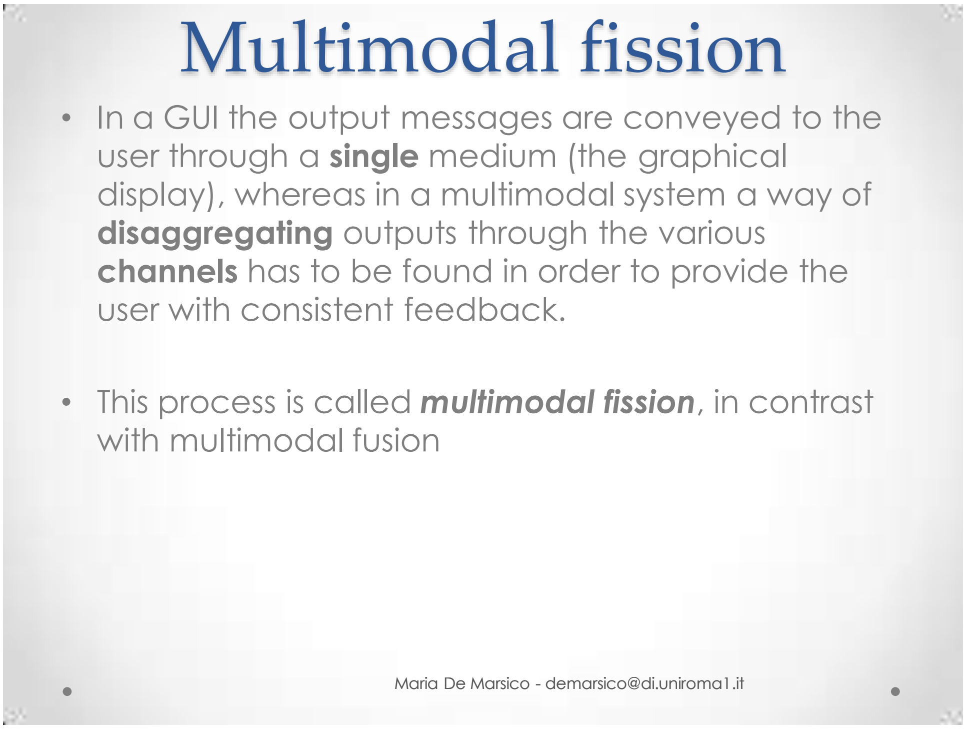


Multimodal timing

- As we have seen, in a multimodal interaction temporal constraints of inputs have to be taken into account and consequently it requires a time-sensitive architecture and the recording of time intervals of each modalities.



Multimodal fission

- In a GUI the output messages are conveyed to the user through a **single** medium (the graphical display), whereas in a multimodal system a way of **disaggregating** outputs through the various **channels** has to be found in order to provide the user with consistent feedback.
- This process is called ***multimodal fission***, in contrast with multimodal fusion

Readings

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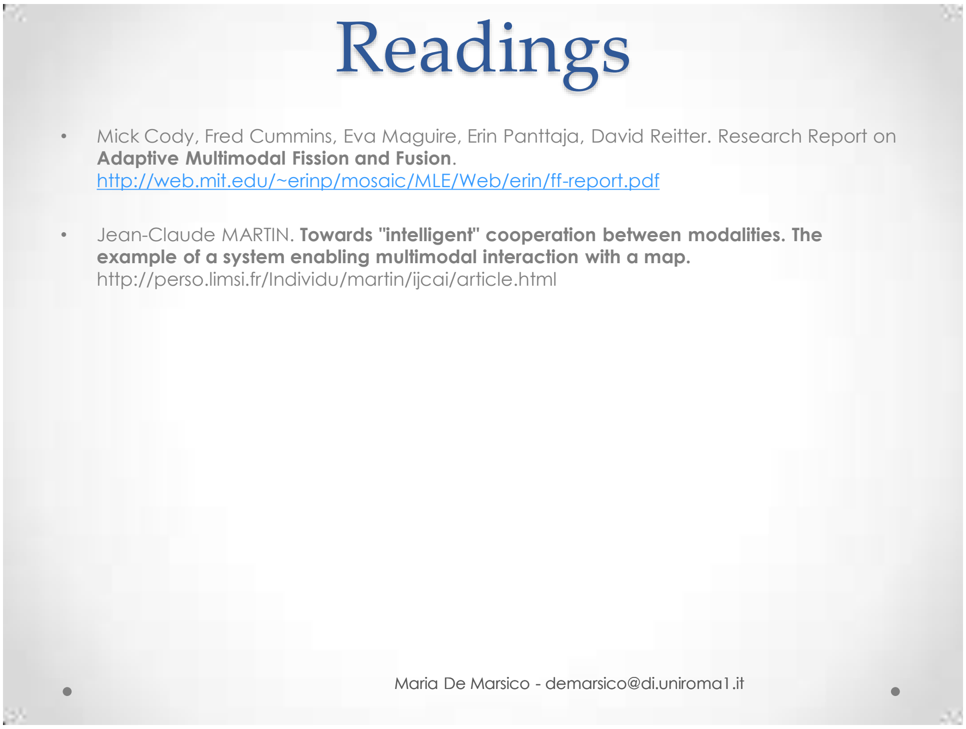
- Hank Liao. **Multimodal Fusion.** http://mi.eng.cam.ac.uk/~hl251/Pubs/liao02mphil.pdf
- Guillermo Pérez, Gabriel Amores, Pilar Manchón. **Two strategies for multimodal fusion.** http://grupo.us.es/julietta/publications/2005/pdf/Two_Strategies.pdf



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- Mick Cody, Fred Cummins, Eva Maguire, Erin Panttaja, David Reitter. Research Report on **Adaptive Multimodal Fission and Fusion.** http://web.mit.edu/~erinp/mosaic/MLE/Web/erin/ff-report.pdf
- Jean-Claude MARTIN. **Towards "intelligent" cooperation between modalities. The example of a system enabling multimodal interaction with a map.** http://perso.limsi.fr/Individu/martin/ijcai/article.html