Formal Methods for Interactive Systems

Part 2 — Foundations

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The Human

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- first priority in the requirements

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Therefore, need to understand

- capabilities
- limitations

of the user

Relevant Human Aspects

(which have a bearing with Computer Systems)

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- how they store information and solve problems
- how they physically manipulate objects

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$\Longrightarrow$ (simplified) model of human processing based on

- Computer Analogy
- Information Processing Theory

Computer Analogy

Computers take a symbolic input, recode it, make decisions about the recoded input, make new expressions from it, store some or all of the input, and give back a symbolic input.

By analogy that is what most cognitive psychology is about.
It is about how most people take in information, how they recode and remember it, how they make decisions, how they transform their internal knowledge states, and how they translate these states into behavioural outputs.

[Lachman et al. 79]
R. Lachman, J. L. Lachman, E. C. Butterfield.
Cognitive Psychology and Information Processing.
Lawrence Erlbaum, 1979.

Organisational Level Analogy

- Central Processing Unit analogous to the mechanism responsible for mental operations to manipulate information
- Information Store analogous to long-term memory
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Unlikely computers humans are also influenced by extenal factors, such as social and organisational environment.

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- Neural Networks

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- Information Processing defines models to characterise the nature of mental processes
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  - use experiments based on analysis of response to confirm and extend the theory

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  - assembled only after content determined

Subjective Analysis

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Subject may report on

- memory strategies developed during experiments
- strategies for problem solving (verbal protocols)
- mental imagery

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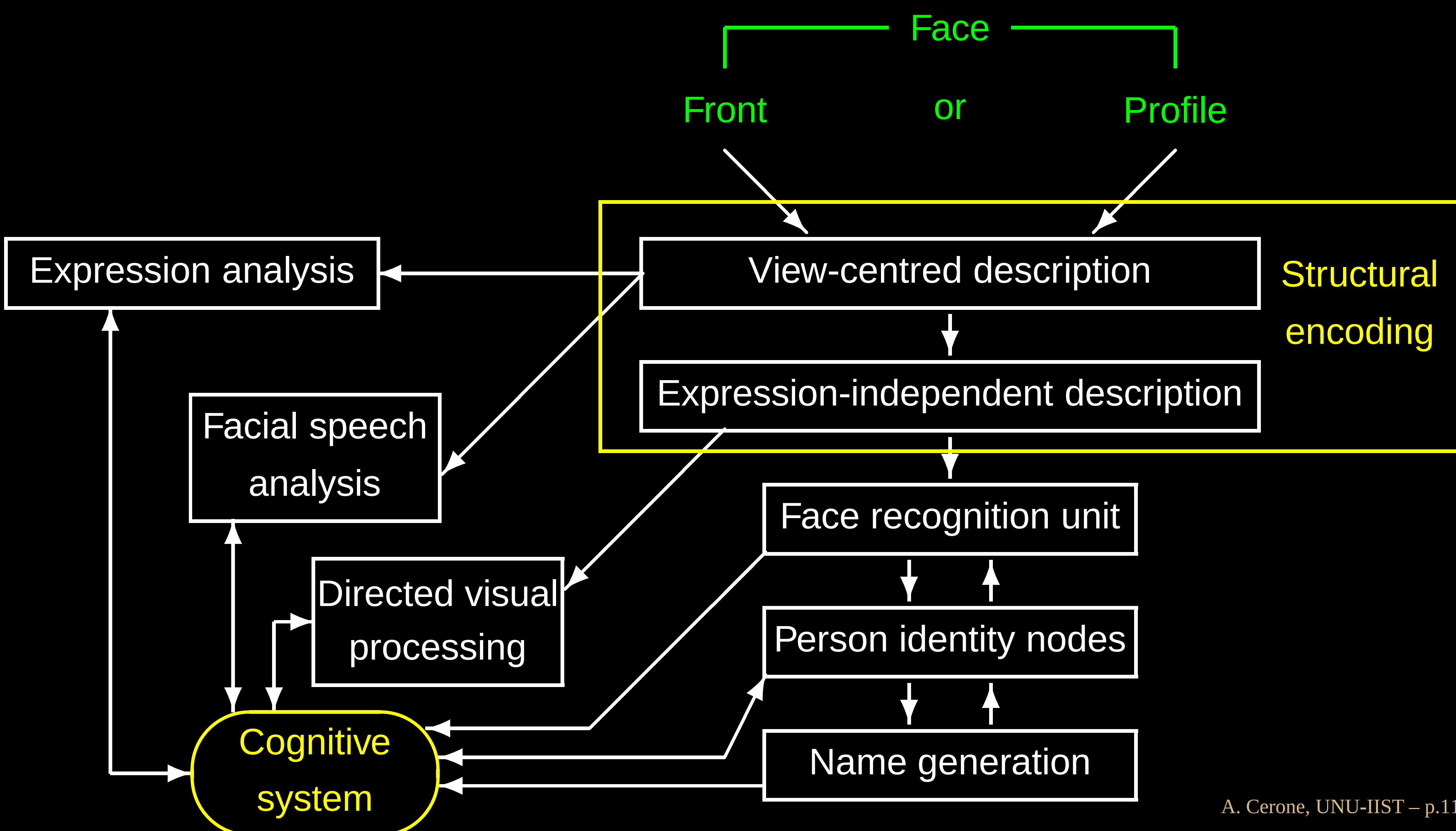
In addition

- principles of operation dictates the behaviour of the system under certain conditions

Bruce-Young Model

proposed in 1982 to account for face recognition



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    (construction from incomplete information)

Vision: Physical Reception

receive light $\Longrightarrow$ electrical energy

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  - cones for colour vision: red, green, blue
    Mainly concentrated in fovea allow fixation

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  - X-cells (mainly in fovea) for early detection of pattern
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  $\Longrightarrow$ these perceptions are crucial in visual interface

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- visual acuity limits detail perception of
  - single lines to 0.5 seconds
  - spaces between lines to 30 seconds

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Increased luminance increases

- visual acuity
- flicker (normally for less than 50 Hz, more noticeable in peripheral vision)

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Colour blindness: inability to discriminate between red and green

Visual Processing Capabilities

- Expectations affect perception
- Visual system compensates, for
  - movement
  - changes in luminance
- Context resolves ambiguity

Context Resolves Ambiguity

13

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2 3 5 7 11 13 17 19 23

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A 13 *C*

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α 13 γ

Illusions

Compensation and ability to solve ambiguities may create illusions:

- Which line is longer?
  Muller-Lyer illusion and Ponzo illusion
- Proof-reading illusion

Muller-Lyer Illusion

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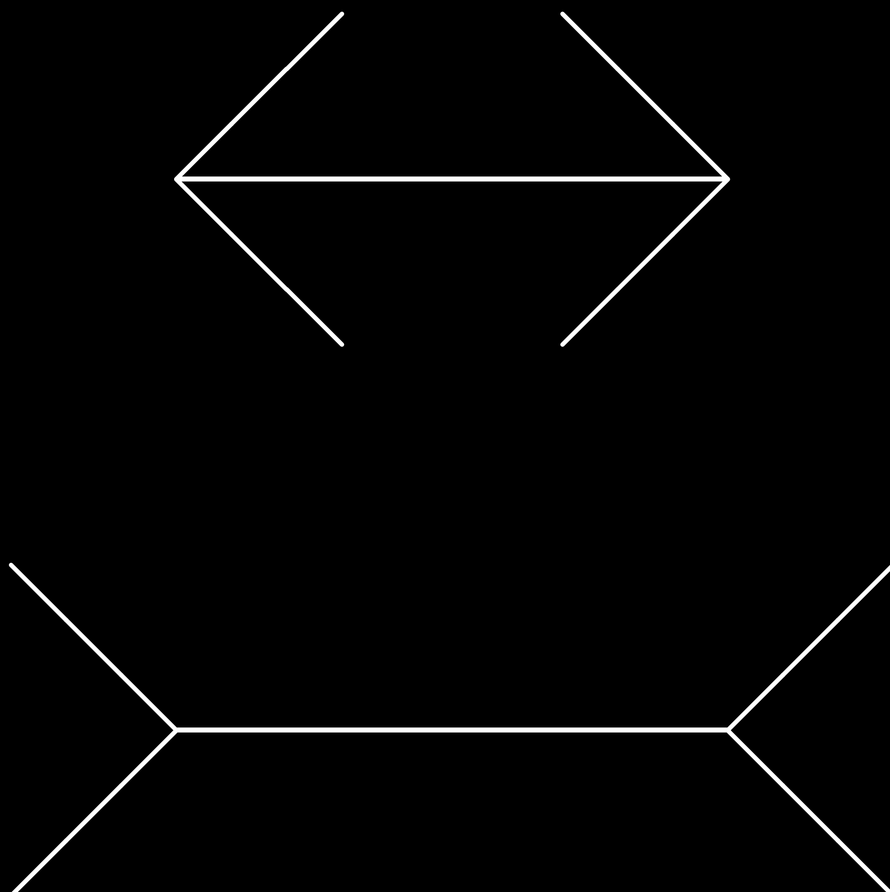

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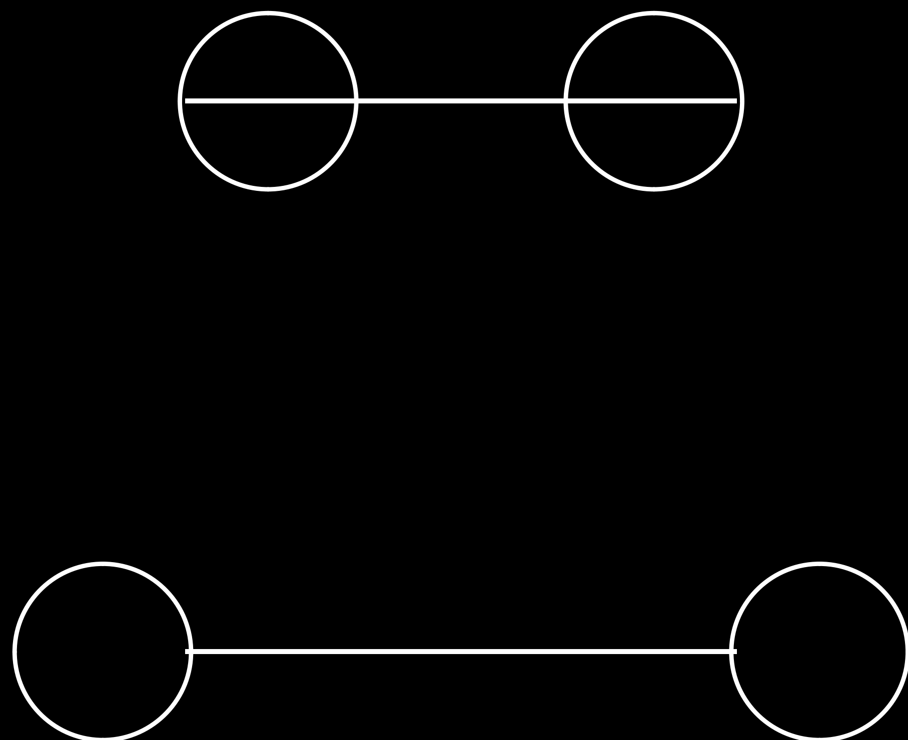

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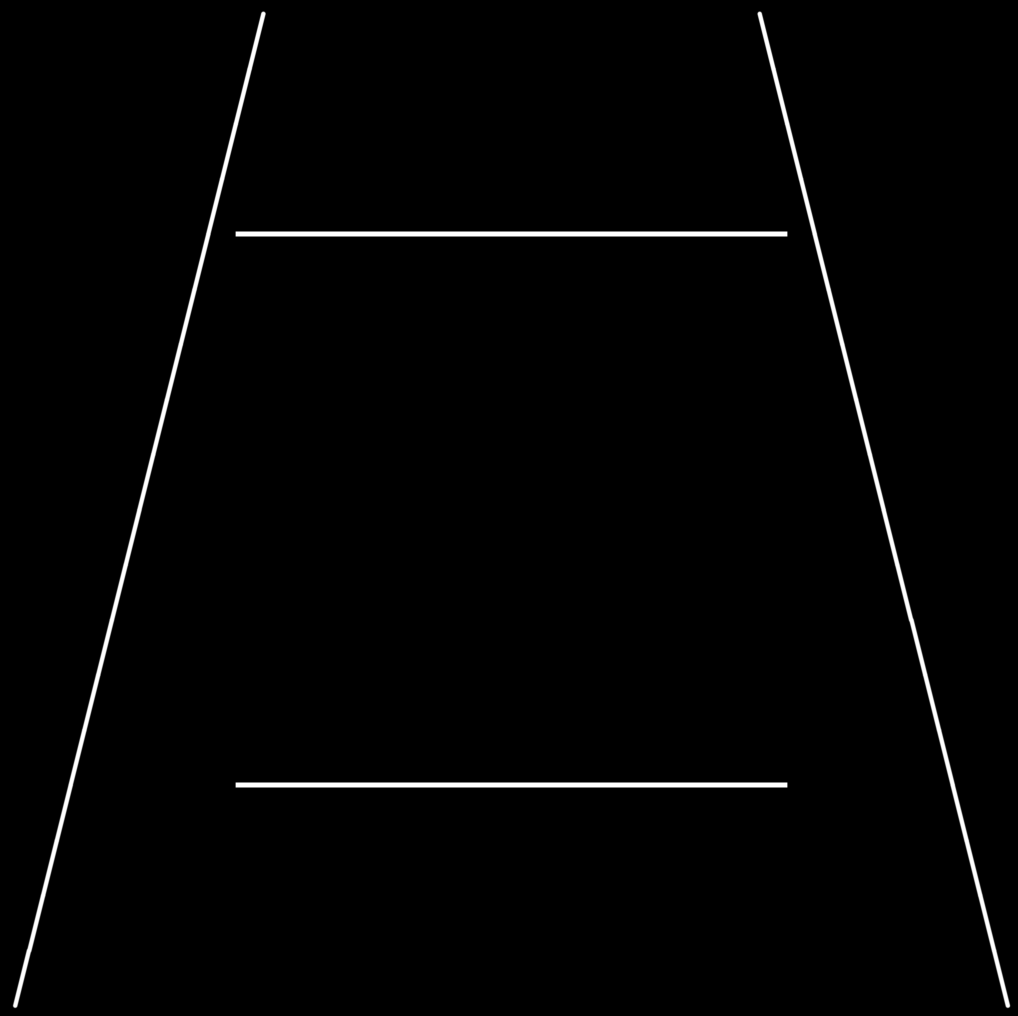

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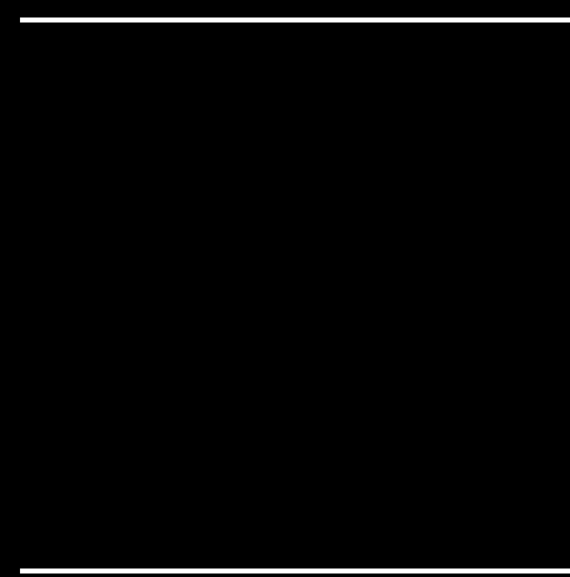

Proof-reading Illusion

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The quick brown

fox jumps over the

the lazy dog

Proof-reading Illusion

Was the text correct?

Reading

Several stages:

- visual pattern perceived after saccades (and regressions) and during fixations (94% of the time)

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- interpreted using knowledge of syntax, semantics and pragmatics

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- potential $=$ more than 1000wpm decreased to 250wpm by
  - incorrect reading practice (regression, short distance, lack of concentration)

Hearing

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- inner ear consists of
  - liquid-filled cochlea
  - contains cilia (hair-like cells)

Sound Properties

- pitch: frequency of the sound waves
  ear can
  - hear frequencies within 20-15,000 Hz
  - distinguish frequencies changes of 1.5 Hz at low frequencies
- loudness: proportional to the amplitude of the sound
- timbre: type of the sound depending on the source of the waves

Processing Sound

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- filtering of the sound received, to ignore background noise and concentrate on important information (e.g., cocktail party effect)

Sound in HCI

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- Recently, use of speach sound
- More potential use of non-speach sound for
  - attracting attention on a critical situation
  - conveying status information
  - as confirmation of carried-out action
  - to support navigation in hypertext

Haptic Perception

- Provides feedback about environment (e.g., button depress)
- Key sense for visually impaired

Sensory Receptors

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  - rapidly adapting (quick reaction)
  - slowly adapting (continuous reaction)

Kinsthesis

- awareness of body and limbs position
- affect confort and performance

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- the muscles perform the movement

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$\Longrightarrow$

- target as large as possible
- distance as small as possible

Human Memory

Sensory Memories

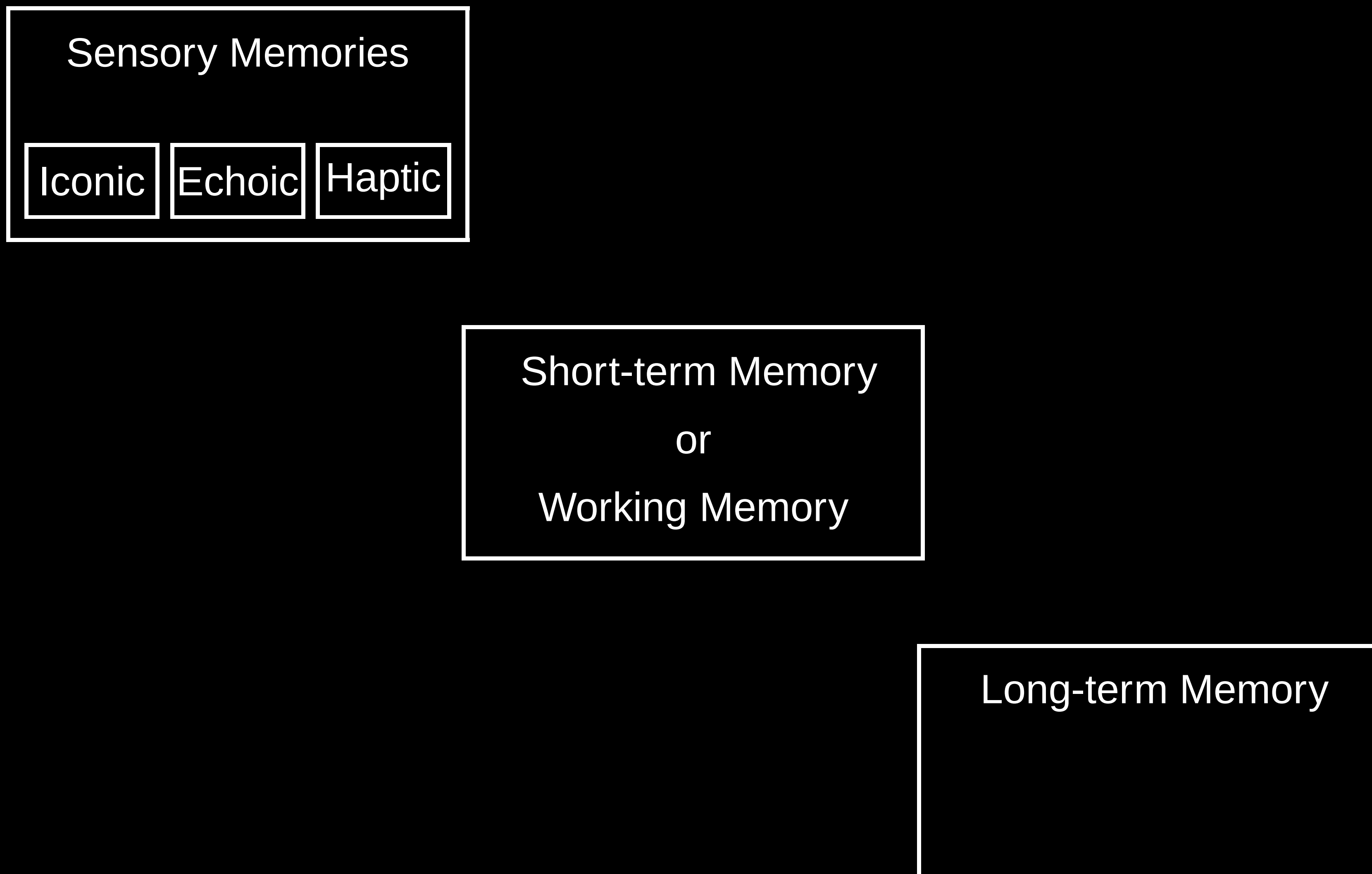
Short-term Memory

or

Working Memory

Long-term Memory

Human Memory



Human Memory

Sensory Memories

Iconic | Echoic | Haptic

information persists
for $<$ 500 ms

Short-term Memory
or
Working Memory

Long-term Memory

Human Memory

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Short-term Memory
or
Working Memory

Attention

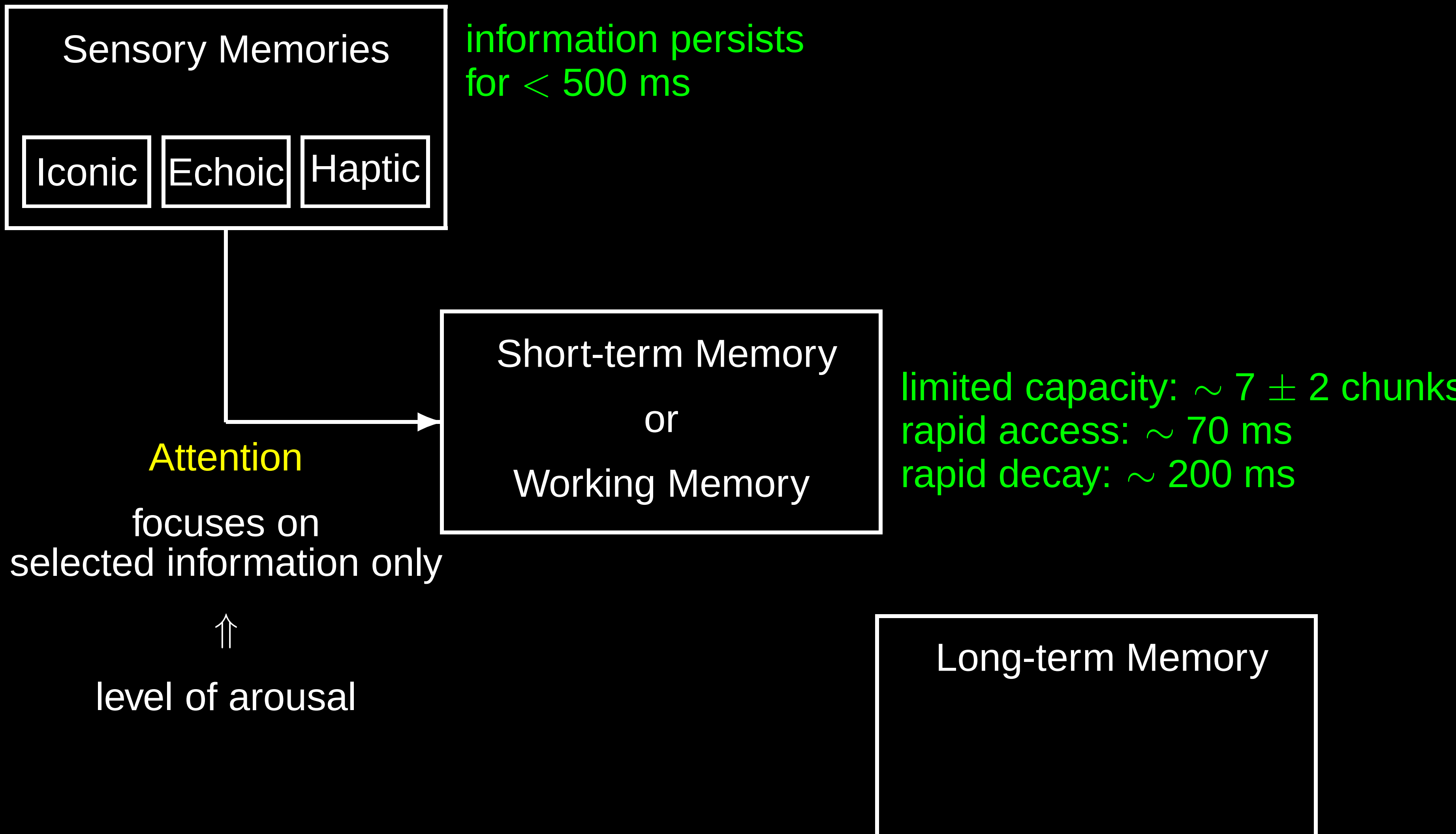
focuses on
selected information only

⇑

level of arousal

Long-term Memory

Human Memory



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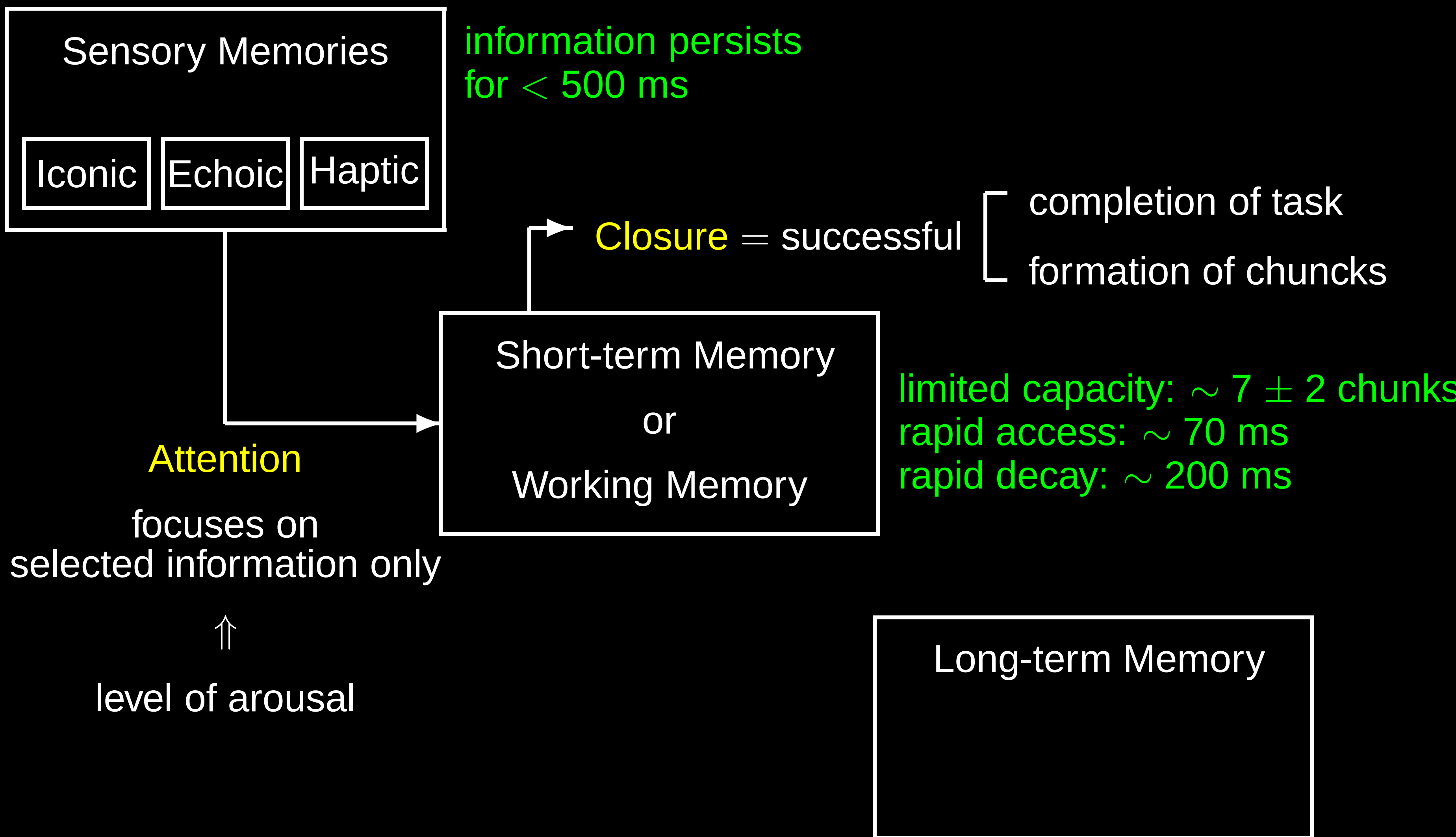

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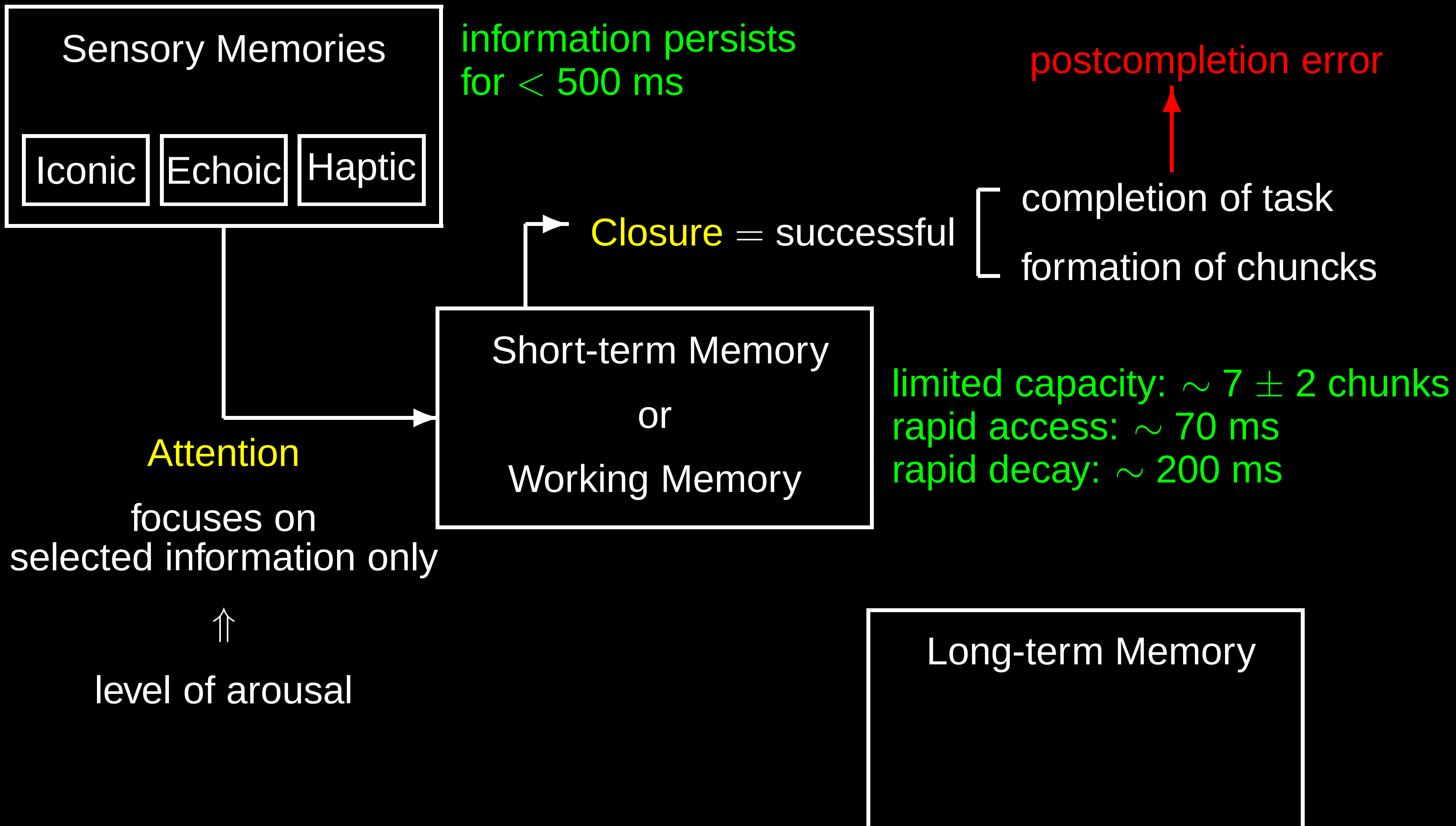

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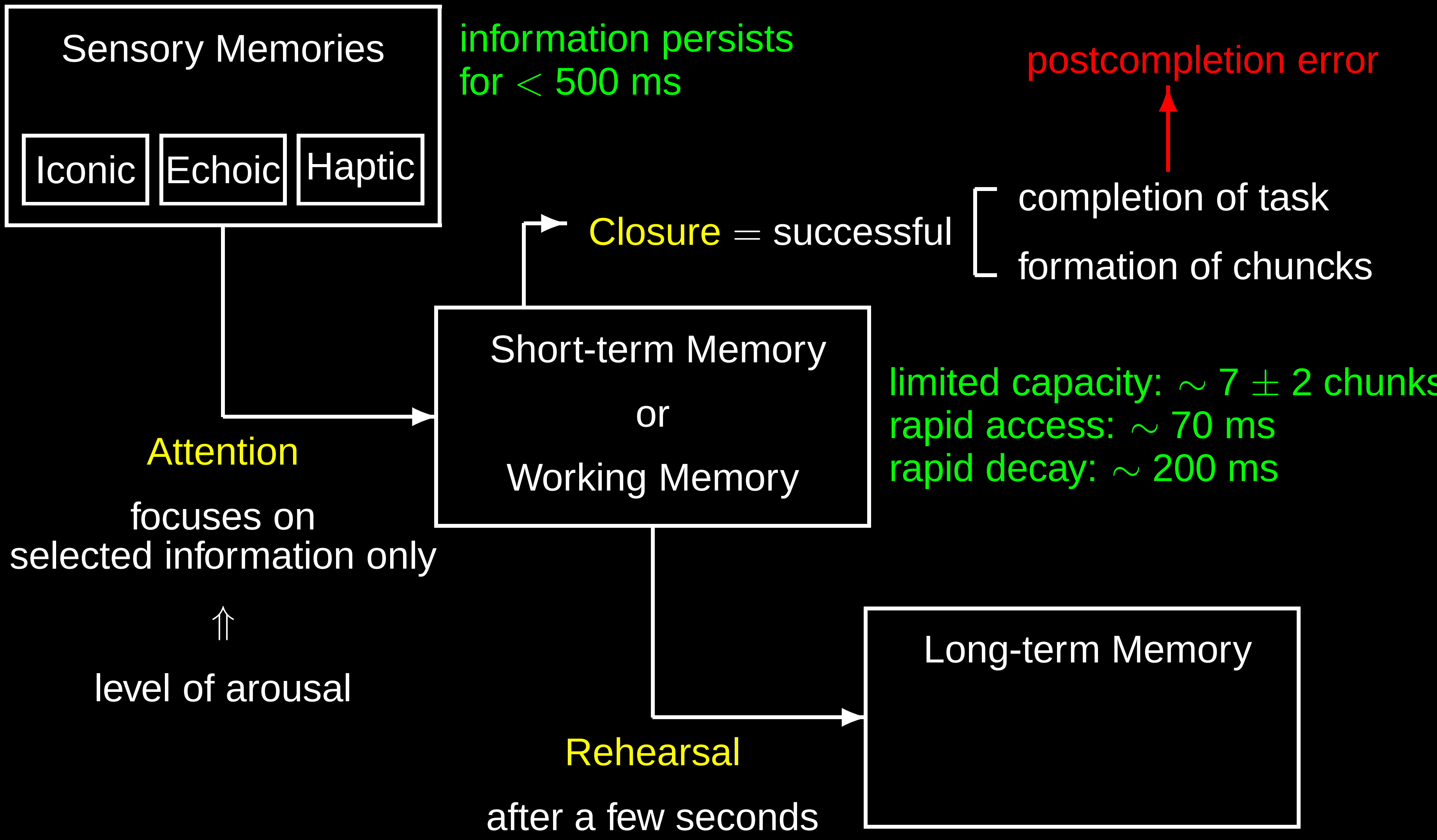

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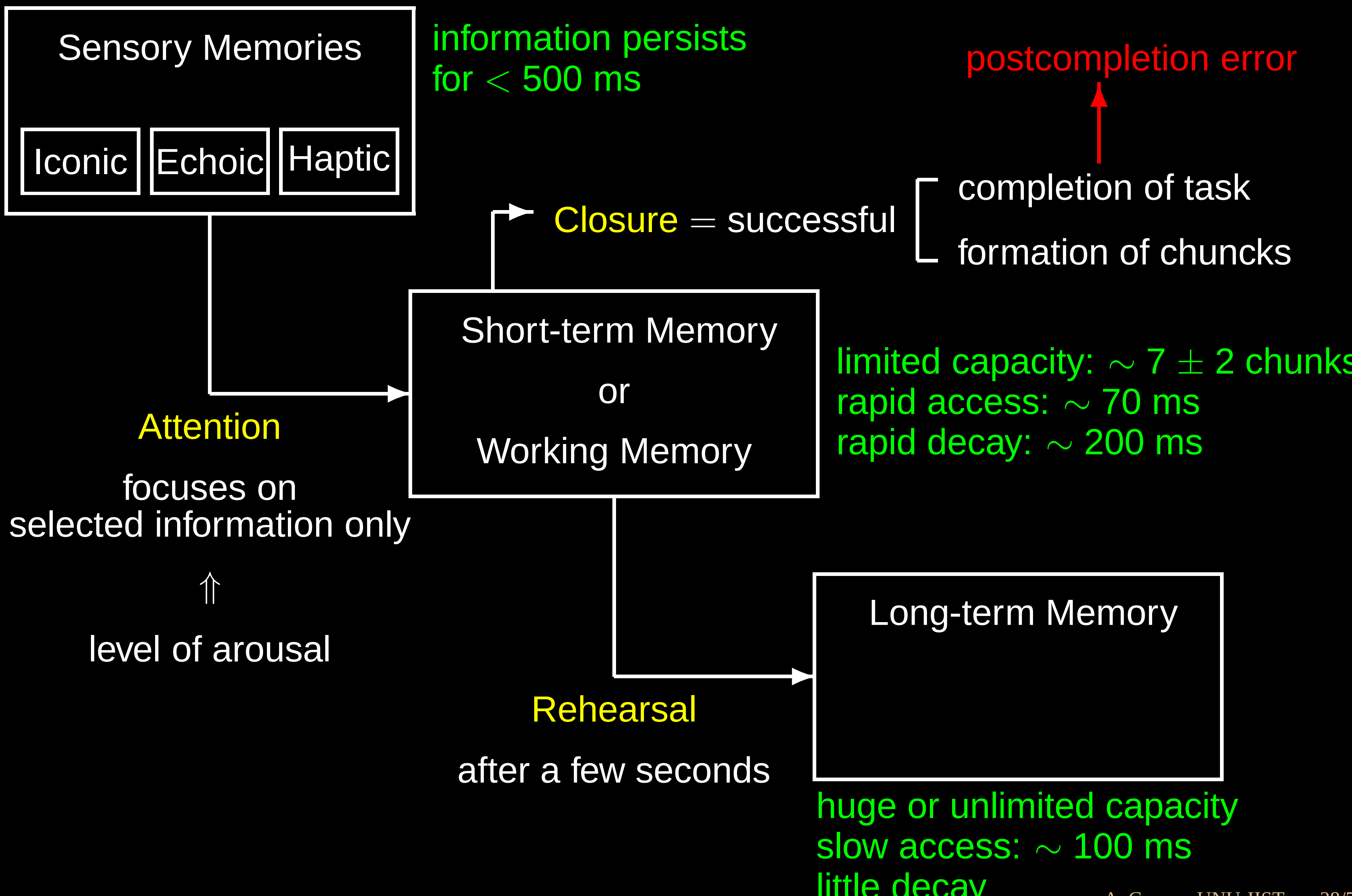

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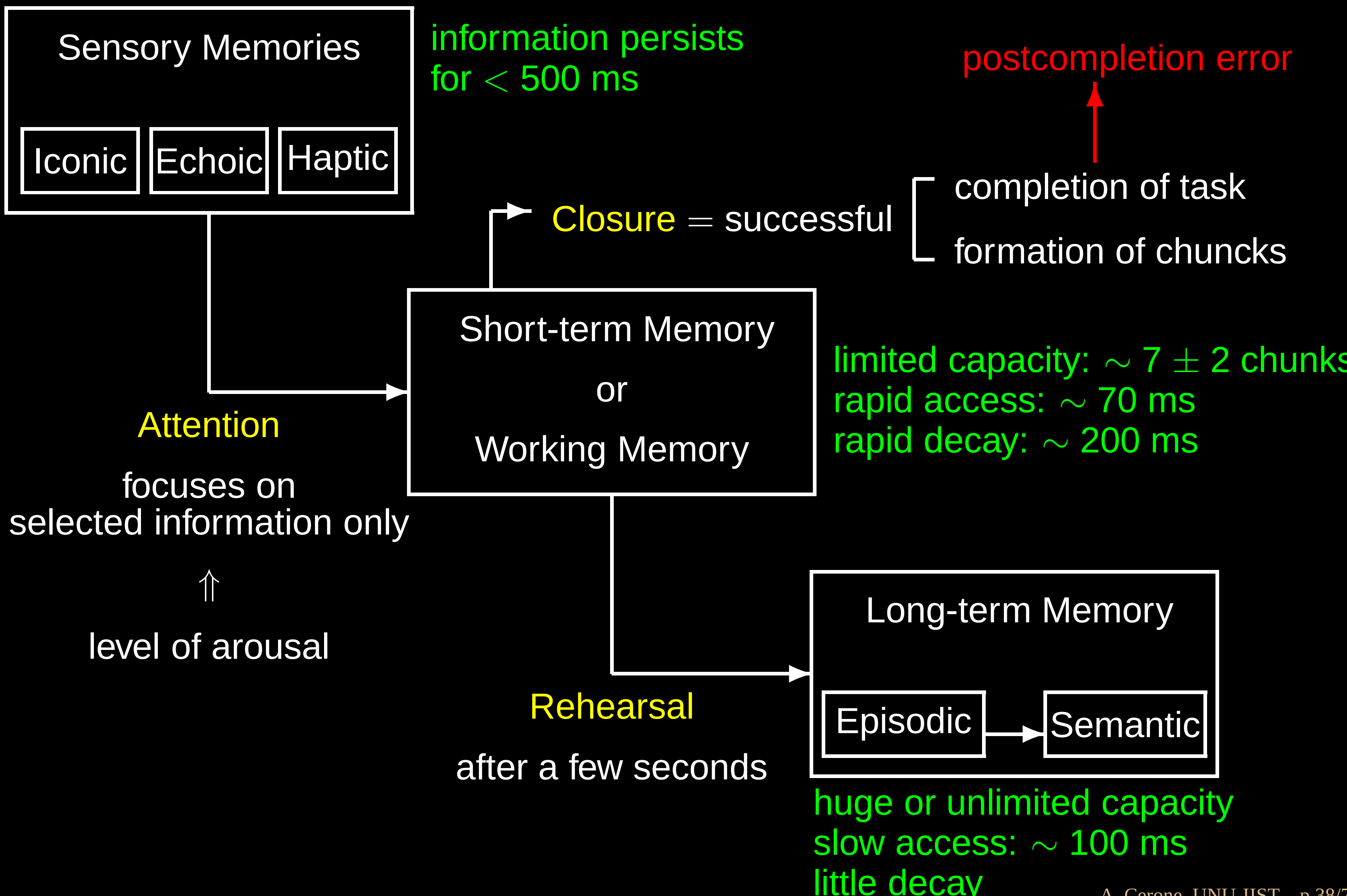

STM: Formation of Chuncks

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382 4915 702

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write down as much of the sequence as you can remember

STM: Formation of Chuncks

8397206419

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GHI SSE QUE NCE IST OOL ONT

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write down as much of the sequence as you can remember

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STOP WRITING NOW!

STM: Formation of Chuncks

3824915702

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GHISSEQUENCEISTOOLONT

STM: Formation of Chuncks

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STM: Formation of Chuncks

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GHISSEQUENCEISTOOLONT

THISSEQUENCEISTOOLONG

THIS SEQUENCE IS TOO LONG

STM Failures

due to

- fail to achieve closure
  - fail to form chuncks
  - fail to complete subtask

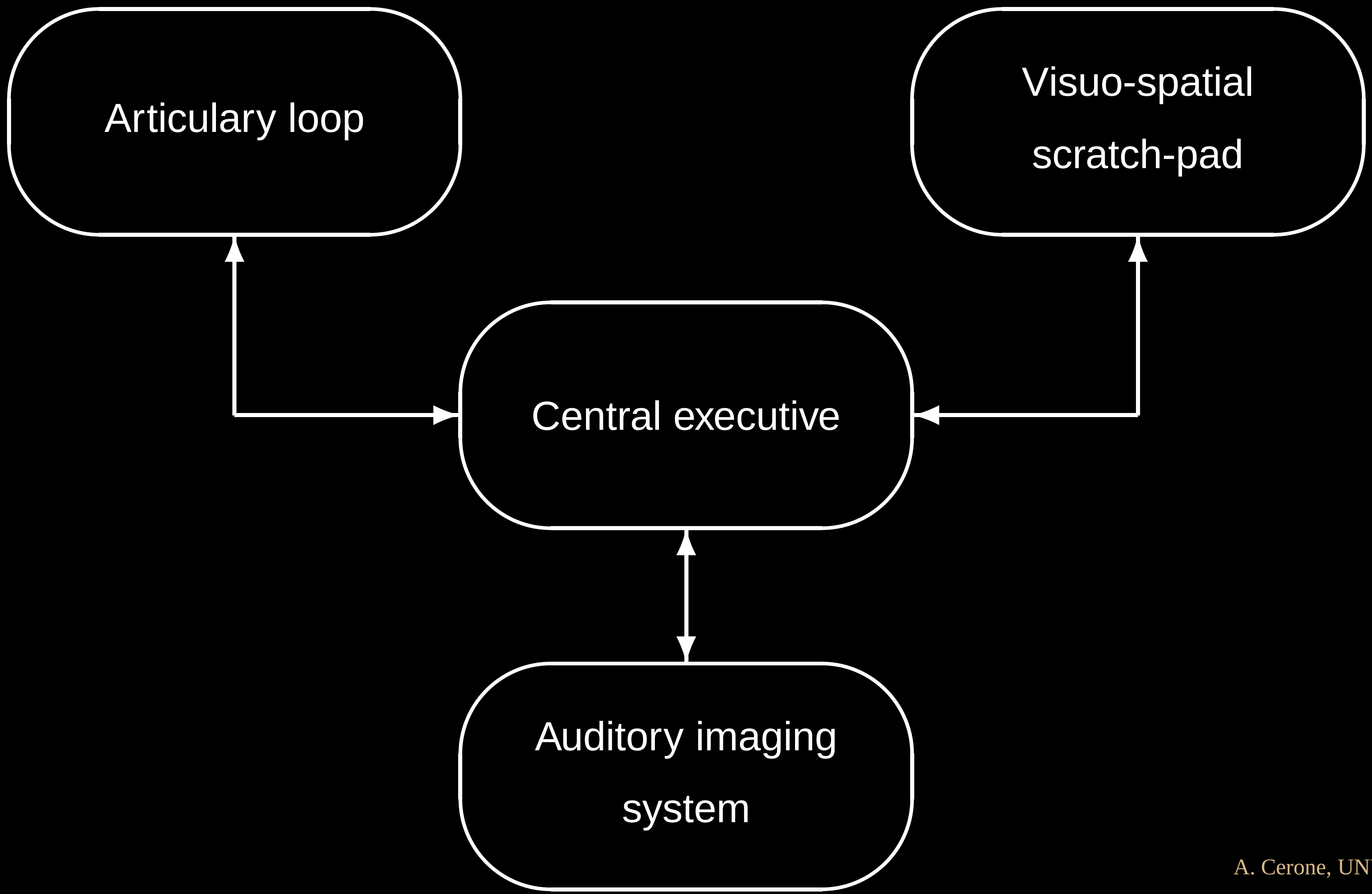
STM Failures

due to

- fail to achieve closure
  - fail to form chuncks
  - fail to complete subtask
- interference from other information/tasks
  - elimination of recency effect in free recall
  - only if tasks use the same channel

Working Memory Model

proposed by Baddley [Baddeley 90]



Long-term Memory

Intended for long-term storage, has two types

- episodic memory
  - contents: events, experiences
  - structure: sequential

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  - structure: semantic networks
  - capabilities: associative access, inference

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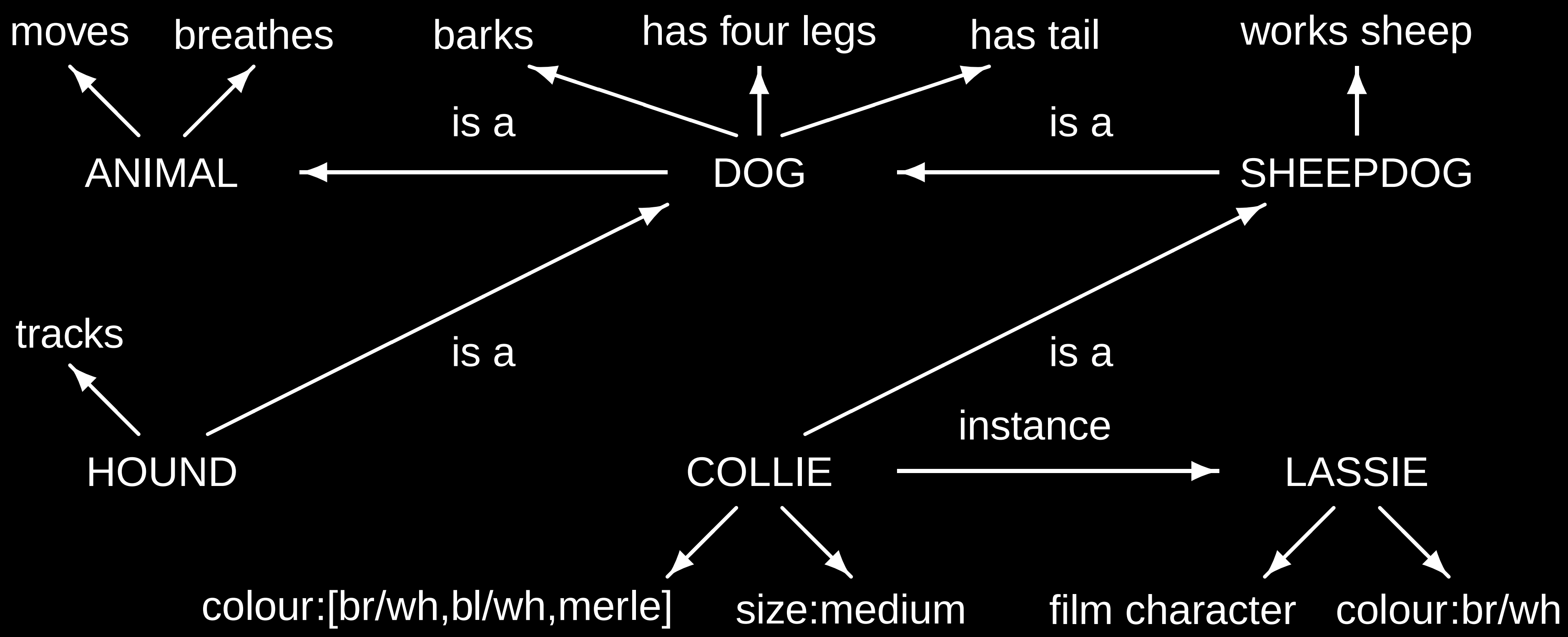
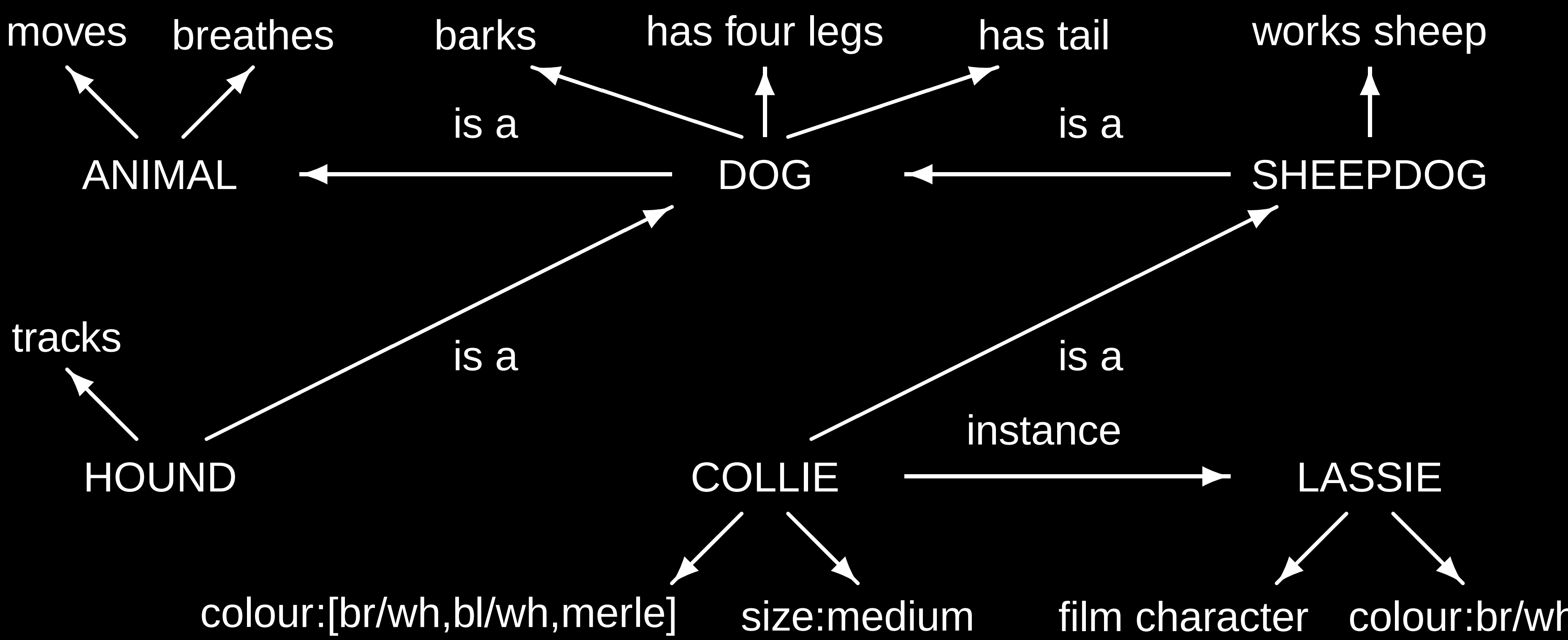
  - capabilities: associative access, inference
  - information derived from episodic memory,

Semantic Networks

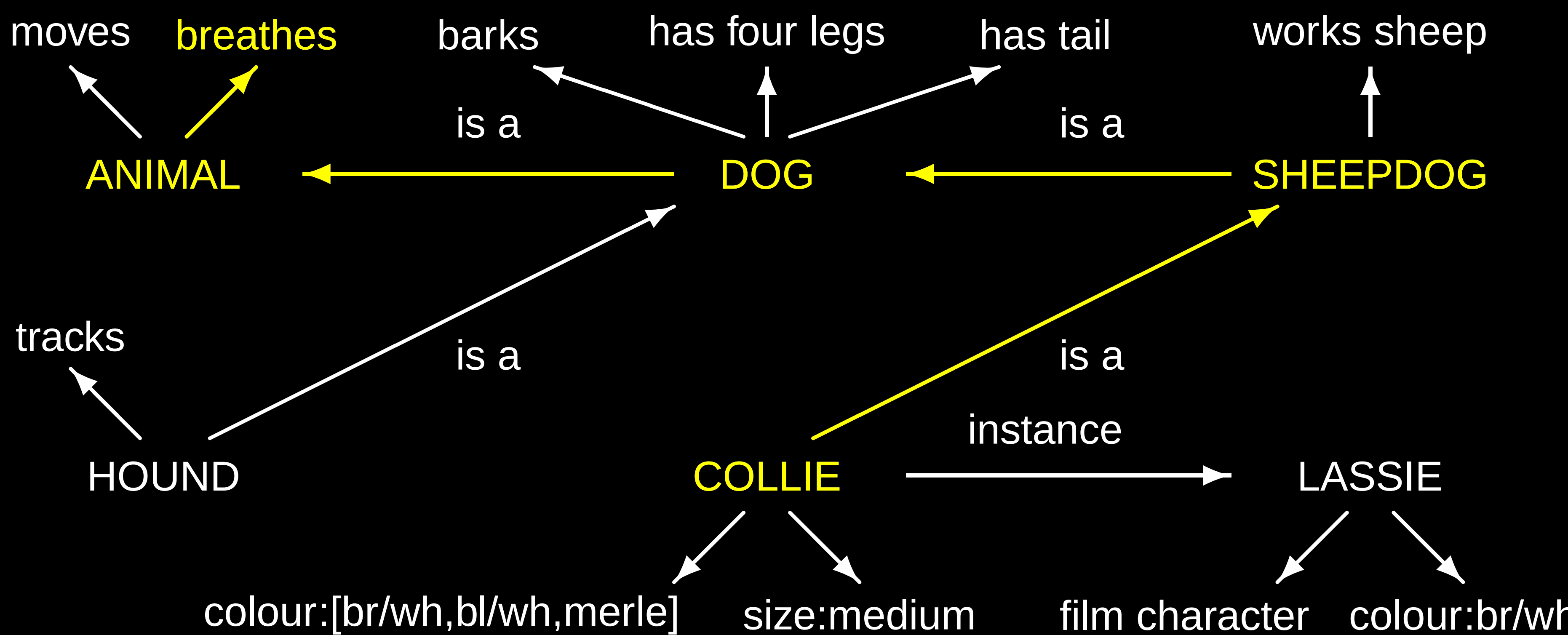


Semantic Networks



Can a collie breathe?

Semantic Networks



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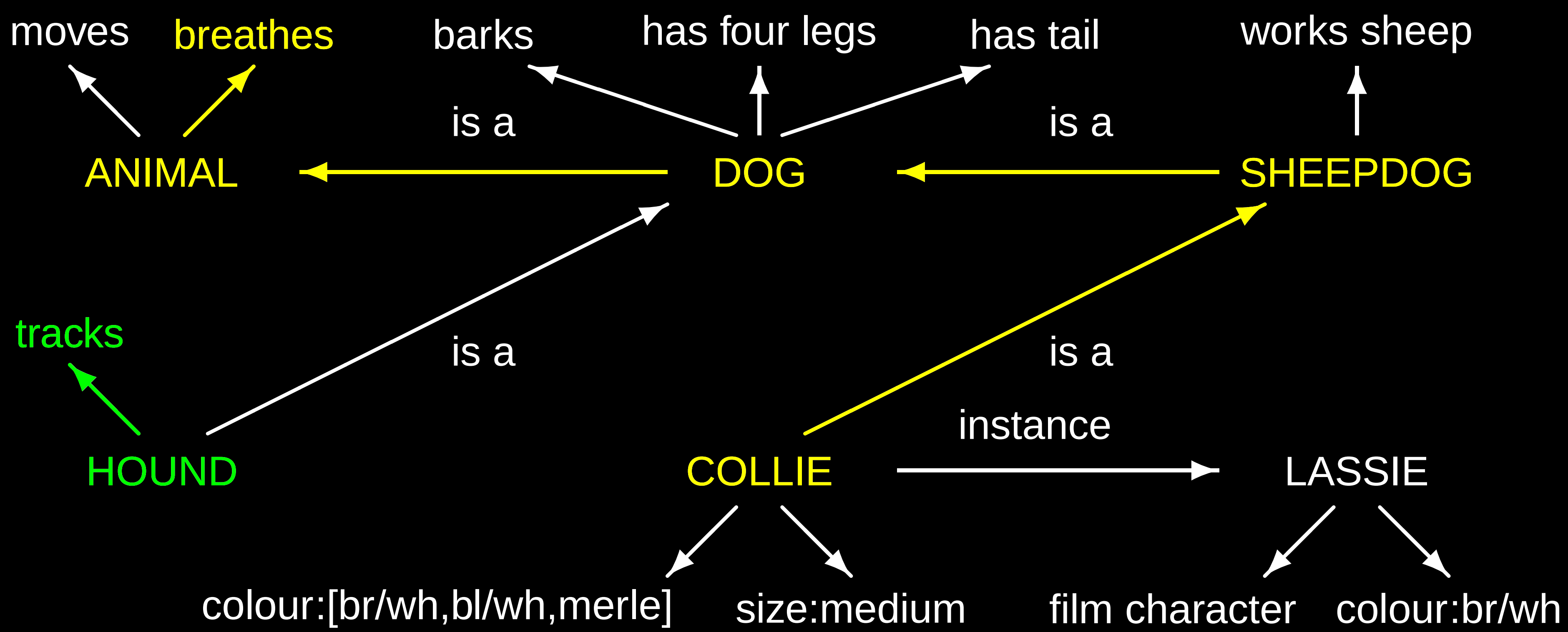

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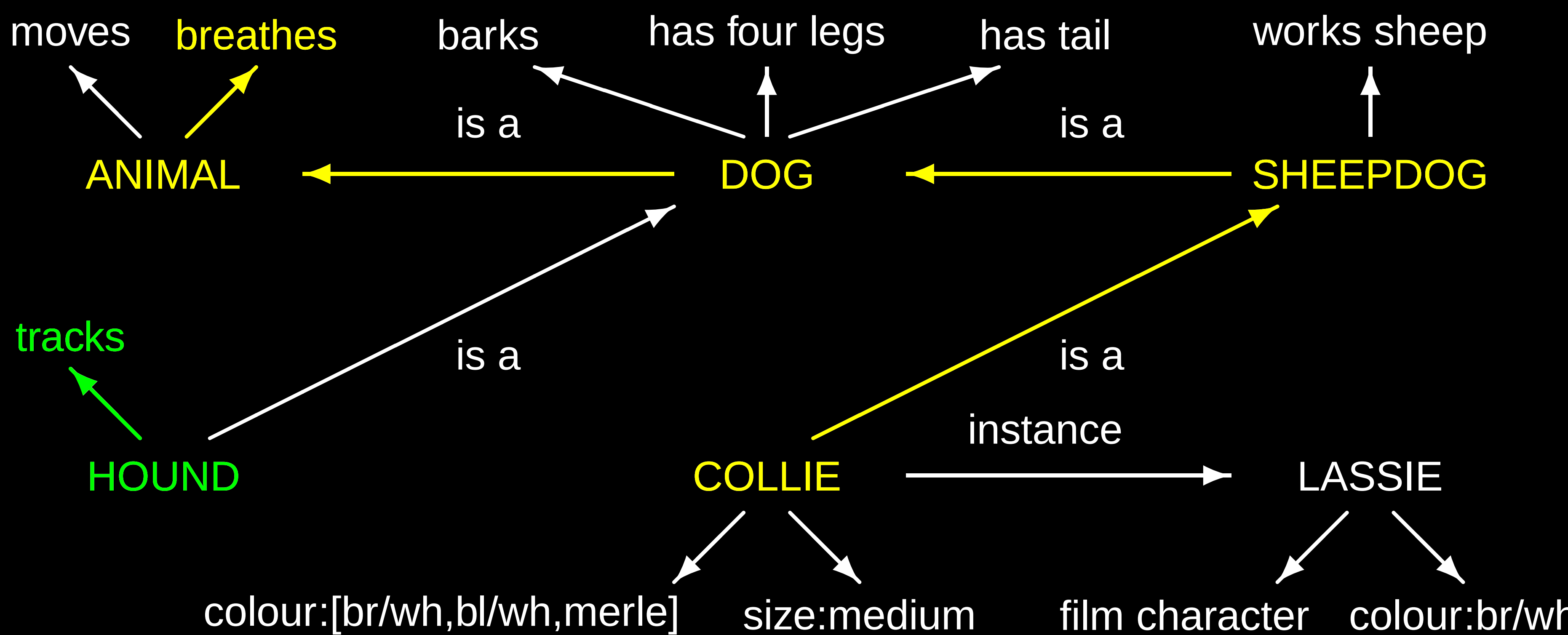


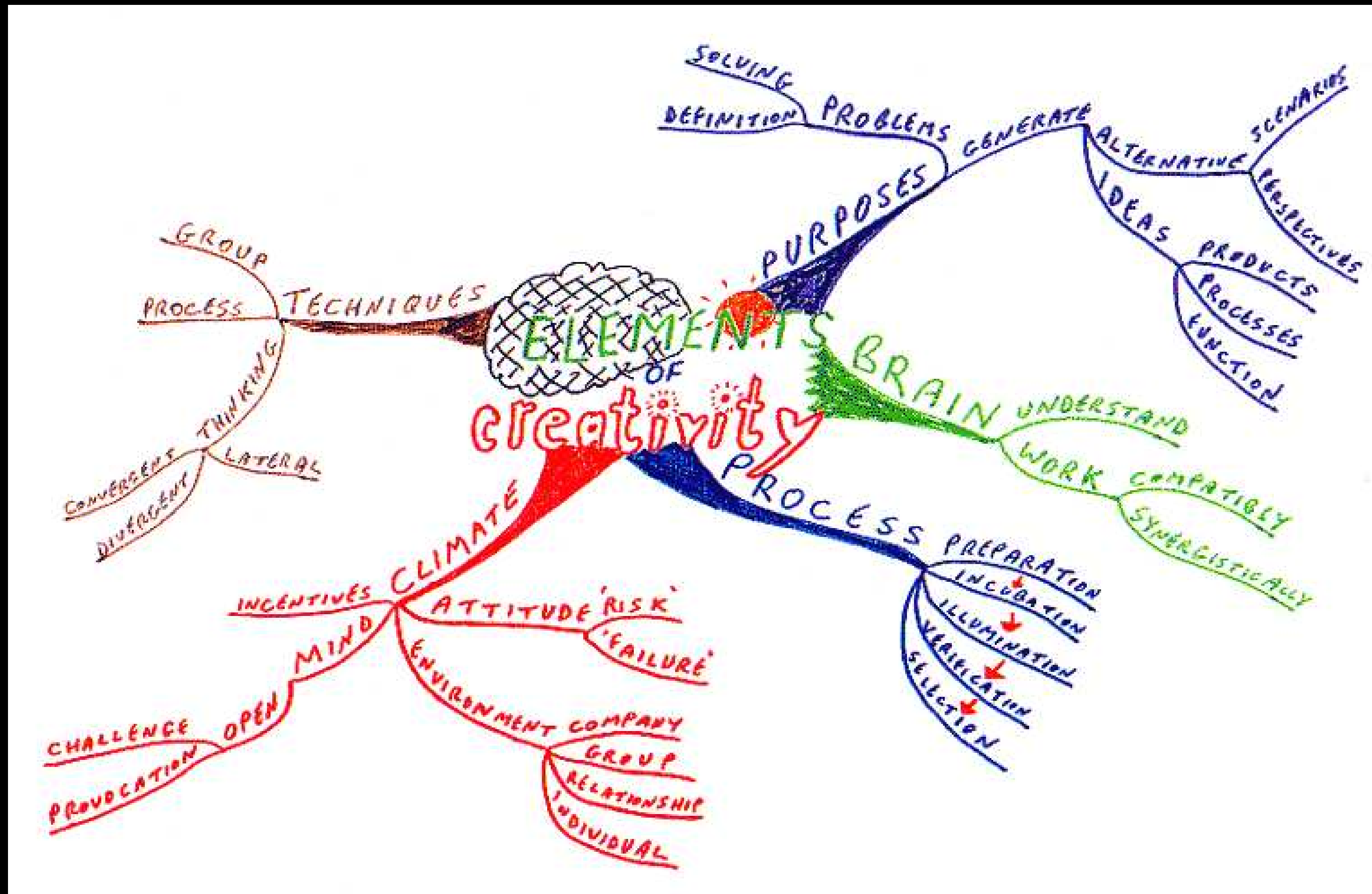
Can a collie breathe?

Does a hund track?

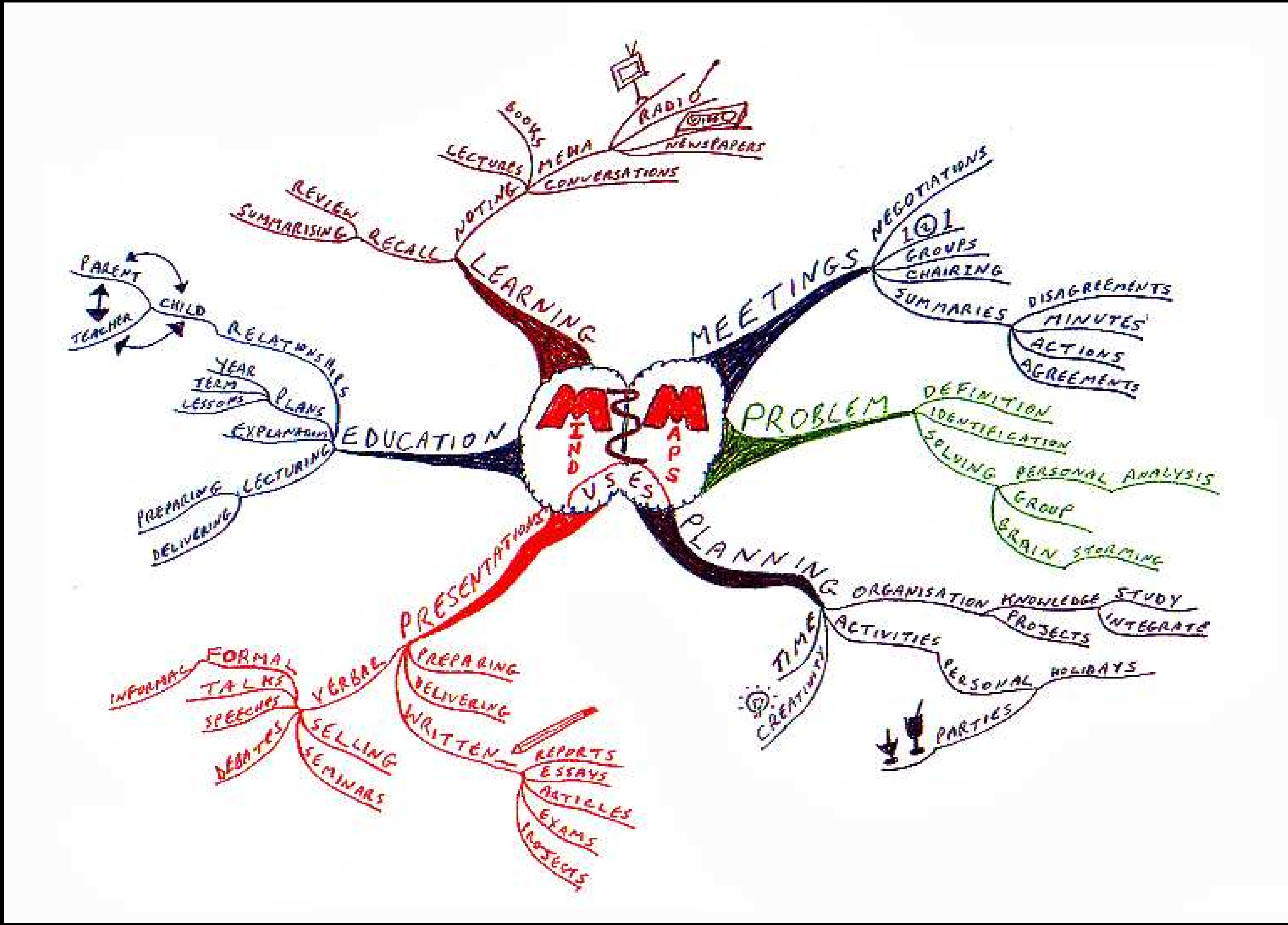
Subjects take longer to answer the first question

[Collins and Quillian 69]

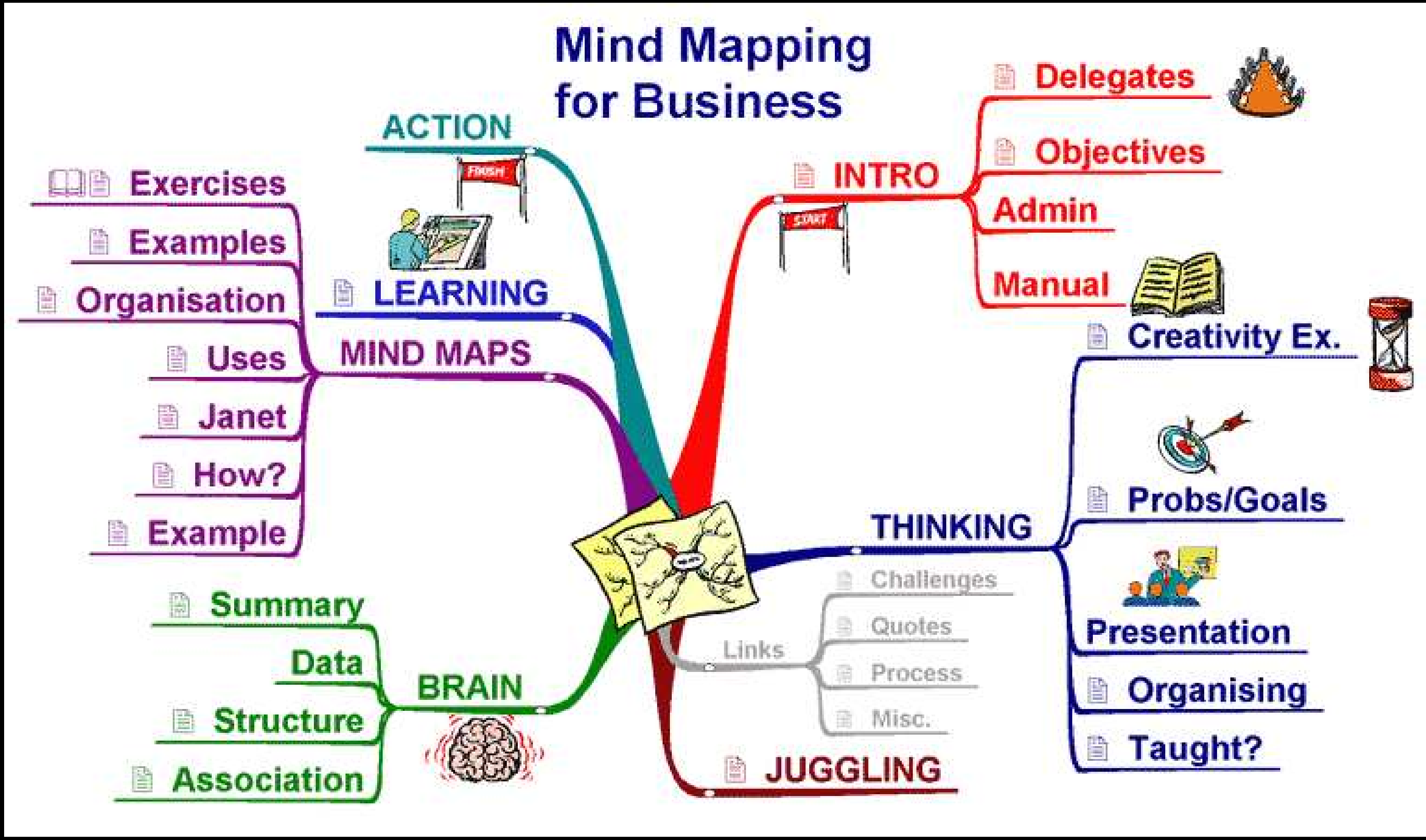
Mind Mapping Example



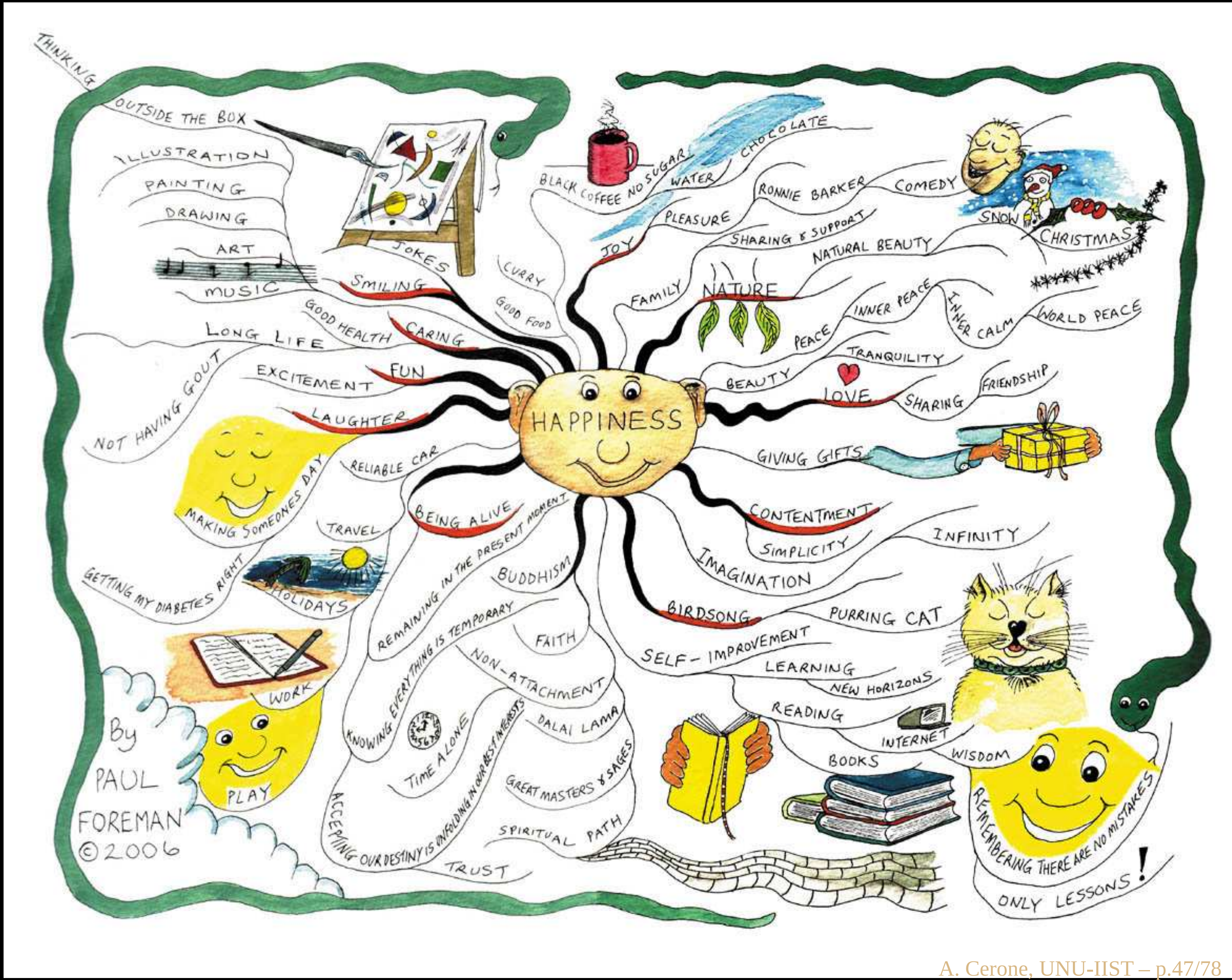
Mind Mapping Uses



Mind Mapping: Business



Mind Mapping: Happiness



Other LTM Structures

Semantics networks represent associations and relationships between single items

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They do not allow the representation of complex object consisting of several items and activities

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Other proposed memory structures (may extend semantic networks):

- frames, consisting of slots containg fixed, default and variable attributes
- scripts, consisting of entry conditions, roles, results, scenes
- production systems consisting of rules

LTM Processes

- rehearsal: repeted exposure to a stimolous or a piece of information $\Longrightarrow$ information moves from STM to LTM (learning information)
- forgetting: information is lost or difficult to retrieve from the memory
- retrieval: search of information previously stored in the memory

Learning Information

can be optimized according to

- total time hypothesis: amount learned proportional to rehearsal time [Ebbinghaus 1885]

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- distribution of practice effects: amount learned proportional to rehearsal time [Baddeley at al. 78]
- structure, meaning and familiarity of the information [Bartlet 32]

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but it is not clear if information is lost or becomes difficult to retrieve from the memory. In fact

- proactive inhibition old information interfears with new

Retrieving Information

in two ways

- recall: information reproduced from memory may be assisted by cues, e.g. categories, imagery [Bousfield 53]

Retrieving Information

in two ways

- recall: information reproduced from memory
  may be assisted by cues, e.g. categories, imagery [Bousfield 53]
- recognition: information gives knowledge that it has been seen before
  less complex information = cue

Memory Techniques: Example

1. bun
2. shoe
3. tree
4. door
5. hive
6. sticks
7. heaven
8. gate
9. wine
10. hen

Thinking

Two general categories of thinking:

- reasoning
- problem solving

In practice, activities that involve each other while thinking

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In practice, activities that involve each other while thinking

Two more specific processes involving thinking

- skill acquisition
- mental modelling

Reasoning

use knowledge

- to draw conclusion
- to infer something new

about the domain of interest

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Different types of reasoning:

- deductive
- inductive
- abductive

Deductive Reasoning

derives logically necessary conclusions from given premises

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Examples

- Premise 1: If he is hungry then he will eat
- Premise 2: He is hungry
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$\Longrightarrow$ shortcut to make interaction more efficient

$\Longrightarrow$ true but invalid deductions

(some people are babies AND some babies cry

Inductive Reasoning

generalises from cases seen to cases unseen

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Examples

- Seen: Every elephant seen has a trunk
- Generalisation: All elephants have trunks

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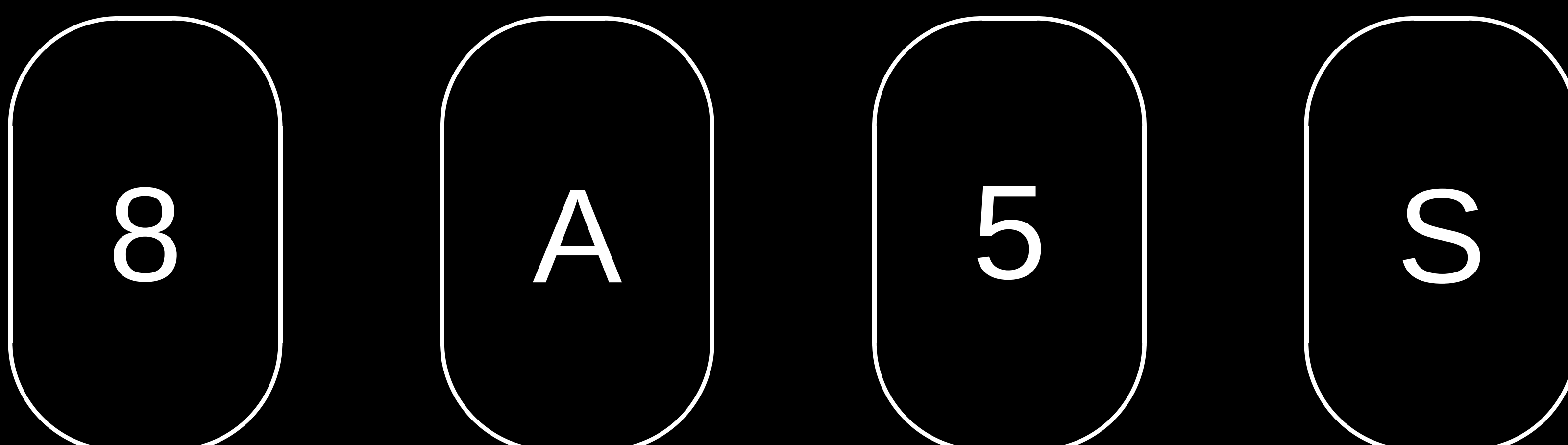
Useful and widly used $\Longleftarrow$ humans are not good at using negative evidence (Wason's cards [Wason 66])

Wason's Cards

Each card has a number on one side and a letter on the other

Which cards need to be picked up to test the truth of the following sentence?

If a card has a vowel on one side it has an even number on the other



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Abductive Reasoning

resoning from event to cause

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Example

- Known fact: Bob is always late at classes
- Event: Bob is absent when the class is starting
- Cause: Bob is late

Abductive Reasoning

resoning from event to cause

Example

- Known fact: Bob is always late at classes
- Event: Bob is absent when the class is starting
- Cause: Bob is late

Unreliable: can lead to false explanation
Bob might be sick and not come to the class at all
$\Longrightarrow$ problems in using interactive systems

Problem Solving

use knowledge to find a solution to an unfamiliar task

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use knowledge to find a solution to an unfamiliar task

Several Theory:

- Behaviourism
- Gesthalt theory
- Information Processing Theories
  - problem space theory
  - analogy

Behaviourism

Psychology should be based solely on observable events, with no mentalistic concepts

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Problem solving is a matter of reproducing known responses (trial and error)

Gestalt Theory

Problem solving is both productive and reproductive

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- productive draws on insight and restructuring the problem

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not enough evidence to explain *insight*

moved away from behaviourism and led to information processing theories

Information Processing Th.

- problem space theory, developed by Newell and Simon [Newell et a. 91], involves generation of states using legal state transition operators

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- problem space theory, developed by Newell and Simon [Newell et a. 91], involves generation of states using legal state transition operators
  - initial state and goal state
  - requires heuristics to select appropriate operator (e.g. means-end analysis)
  - limited by STM capacity and information retrival time
- analogy, to map knowledge related to a similar known domain to the new domain

Skill Acquisition

- we have seen problem solving, which concerns with unfamilian problems
- but most problems we face are not completely new:

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Expert behaviour characterised by

- larges chunks of information to optimize STM
- conceptual rather than superficial grouping of problems $\Longrightarrow$ information structured more effectively

Mental Models

People build their own theory to understand the causal behaviour of systems

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Mental models are

- partial: people
  - do not have full understanding of the system
  - neglect what they believe irrelevant
  - interpret the world using conventions
- unstable: subject to change
- often unscientific and sometimes even based on superstition rather than evidence

Errors

Several different kinds of errors:

- slips: results from a change of context or a closure in skilled behaviour

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It is responsability of the interface designer to take conventions, popular beliefs, possible slips and memory limitations into account

Individual Difference

- long term:
  - sex
  - physical capabilities
  - intellectual capabilities

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- changing:
  - age

The Computer

The participant in the interaction that run a program

[Thimbleby 90]

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The participant in the interaction that run a program

[Thimbleby 90]

Definition can be applied to a vast class of devices from a light switch to a powerful computer

The Interaction

The communication between User and System

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Terminology

- interactive system: to accomplish goals from some application domain

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- a task language $=$ User's language

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Terminology

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- a core language = System's language
- a task language = User's language

Single User Perspective: if the human participant is a group, then users other than User are part of System

Norman's Model

proposed by Norman [Norman 88]

- establishing the goal

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- establishing the goal
- forming the intention

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Norman's Model

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- forming the intention
- specifying the action sequence
- executing the action
- perceiving the system state
- interpreting the system state
- evaluating the system state wrt the goal and intention

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- gulfs of execution: difference between
  - User's formulation of the action to reach the goal, and
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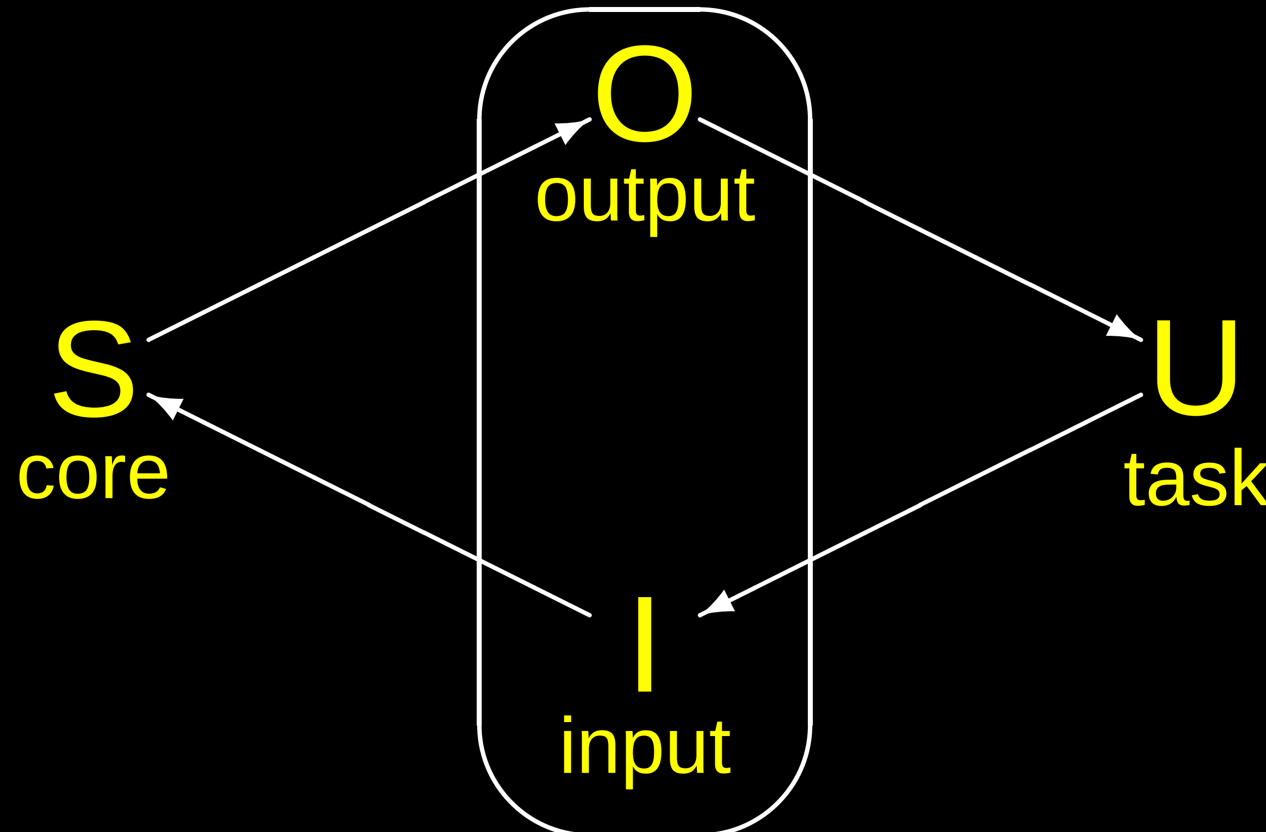
Limitation: model does not include System's communication through the interface

Interaction Framework

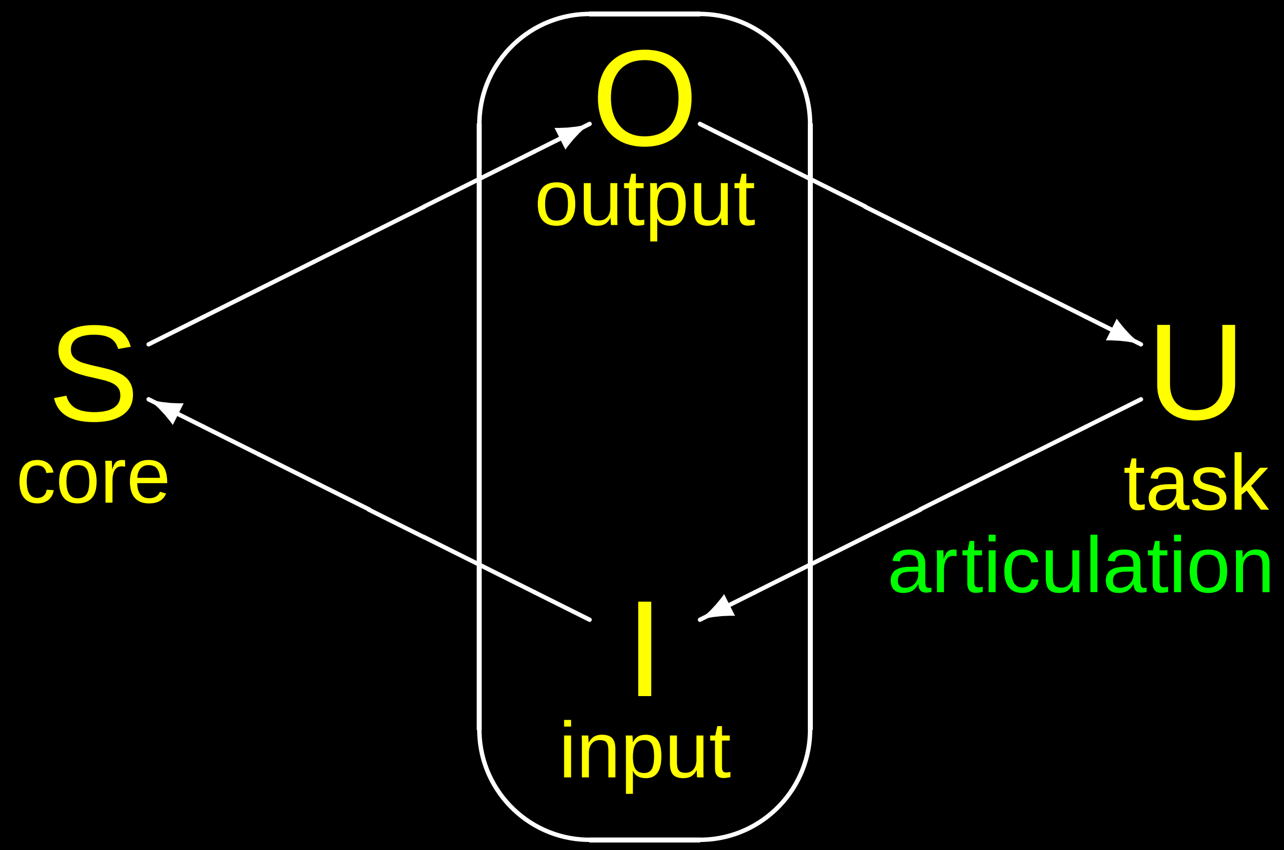
proposed by Abowd and Beale as an extension of Norman's model [Abowd and Beale 88]



consists of 4 parts (S, U, O, I) each with its own unique language

Interaction Framework

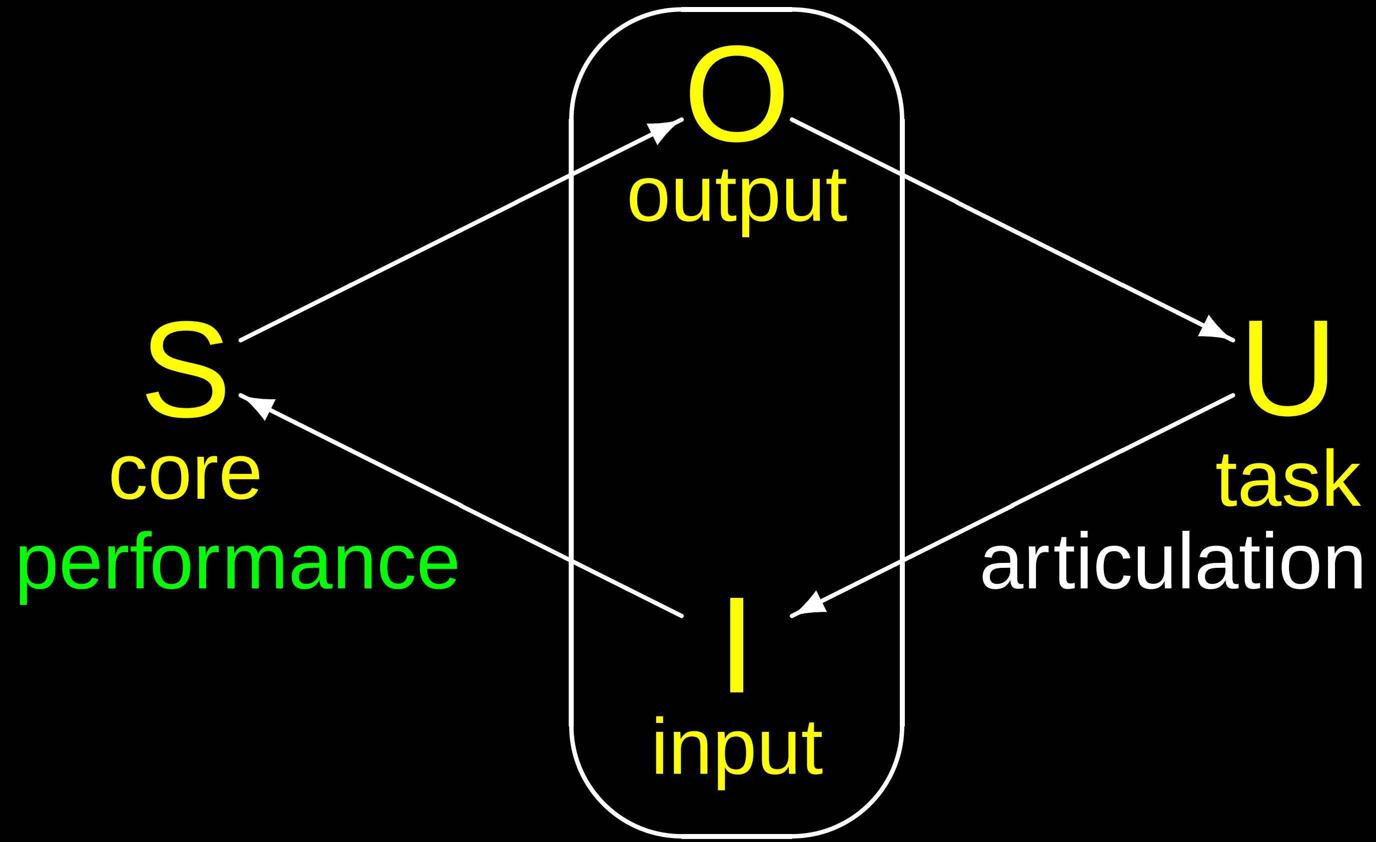
formulation of User's goal and task to achieve it (articulated using input language)



How clearly the psychological attributes defining the task are mapped onto the input language?

Interaction Framework

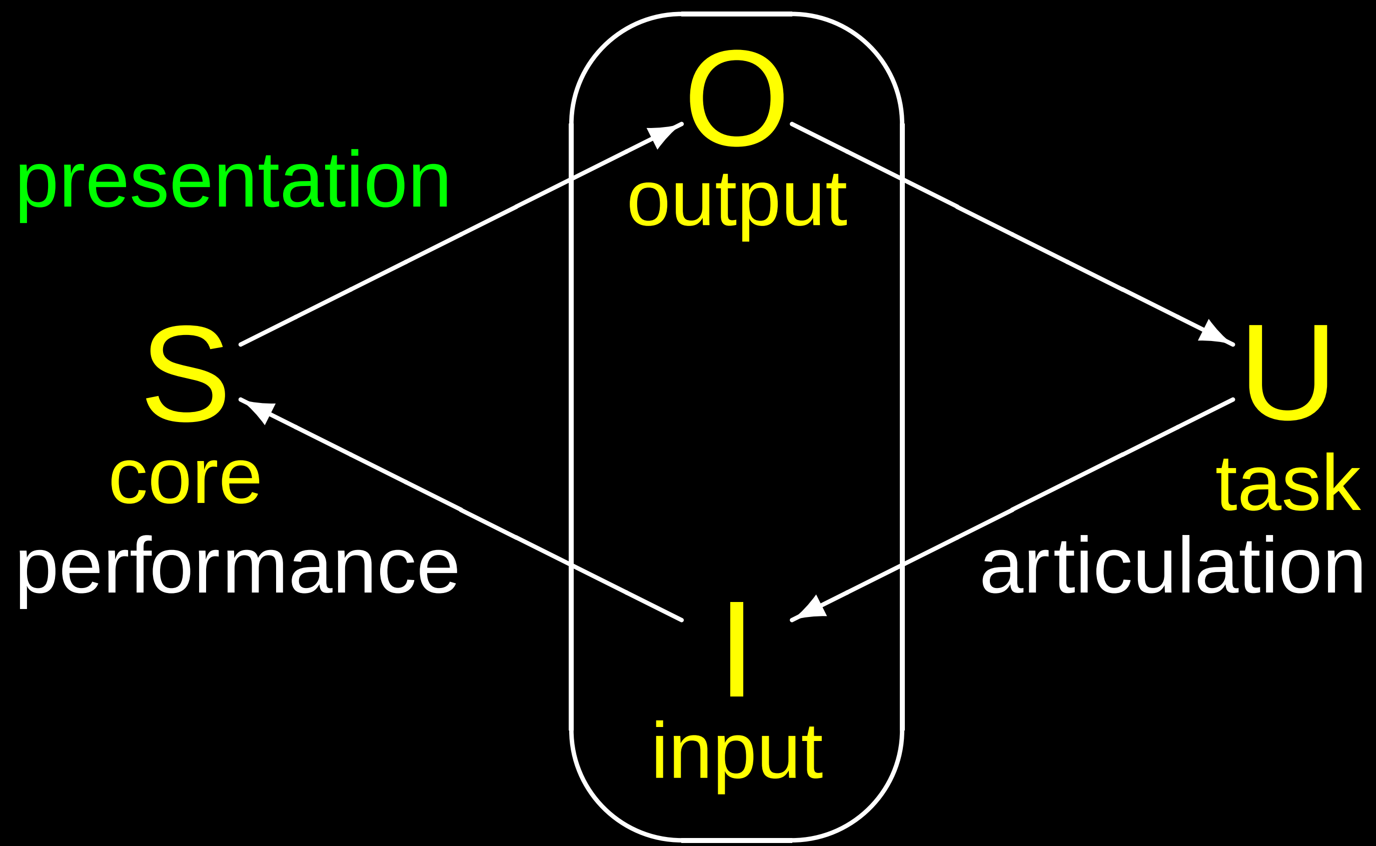
translation of input into core language as operations to be performed by the System



Does the translation input-to-core directly cover as much System states as possible?

Interaction Framework

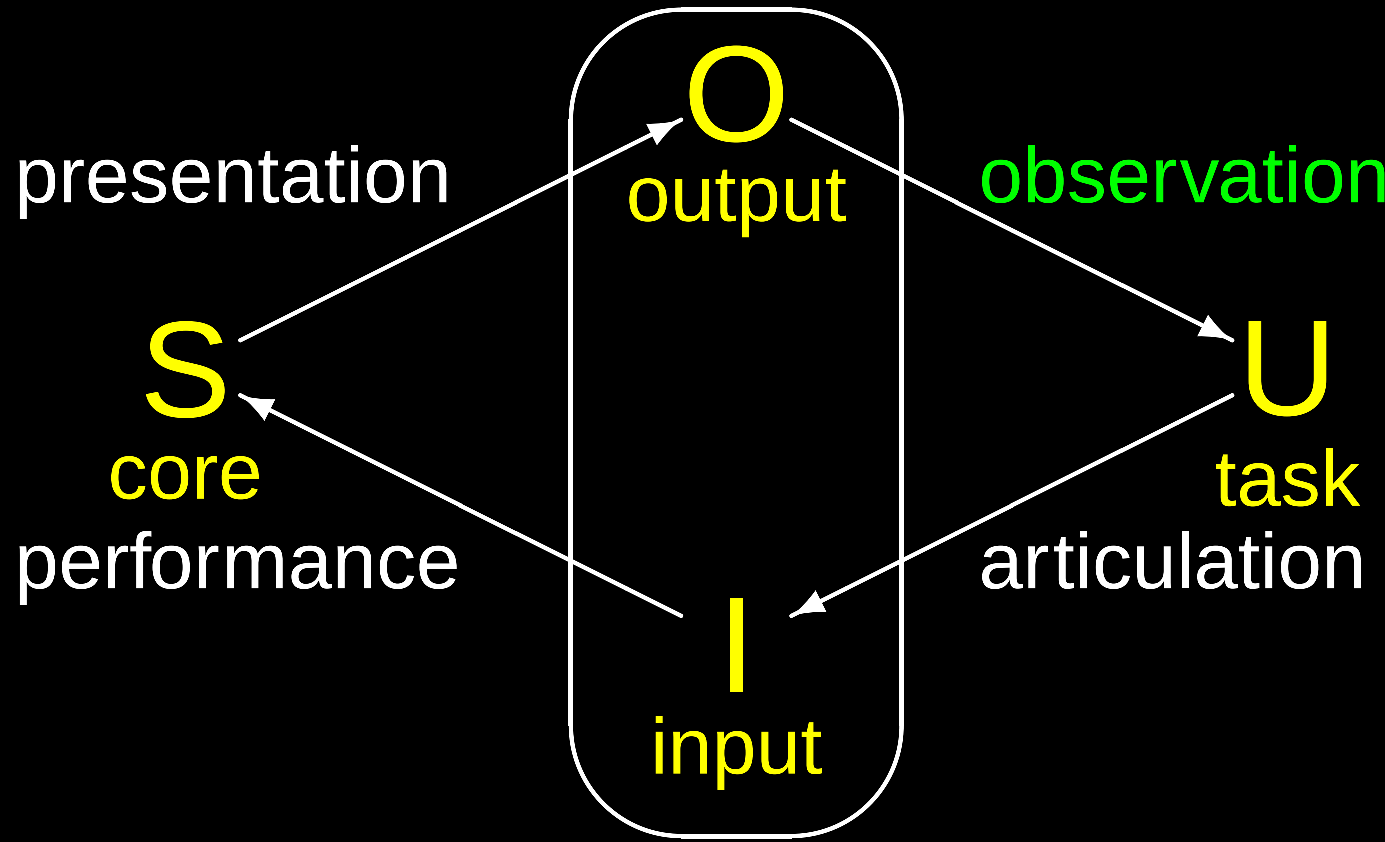
the new System state is presented to the User in the output language



Does the translation core-to-output preserve relevant System attributes from the domain?

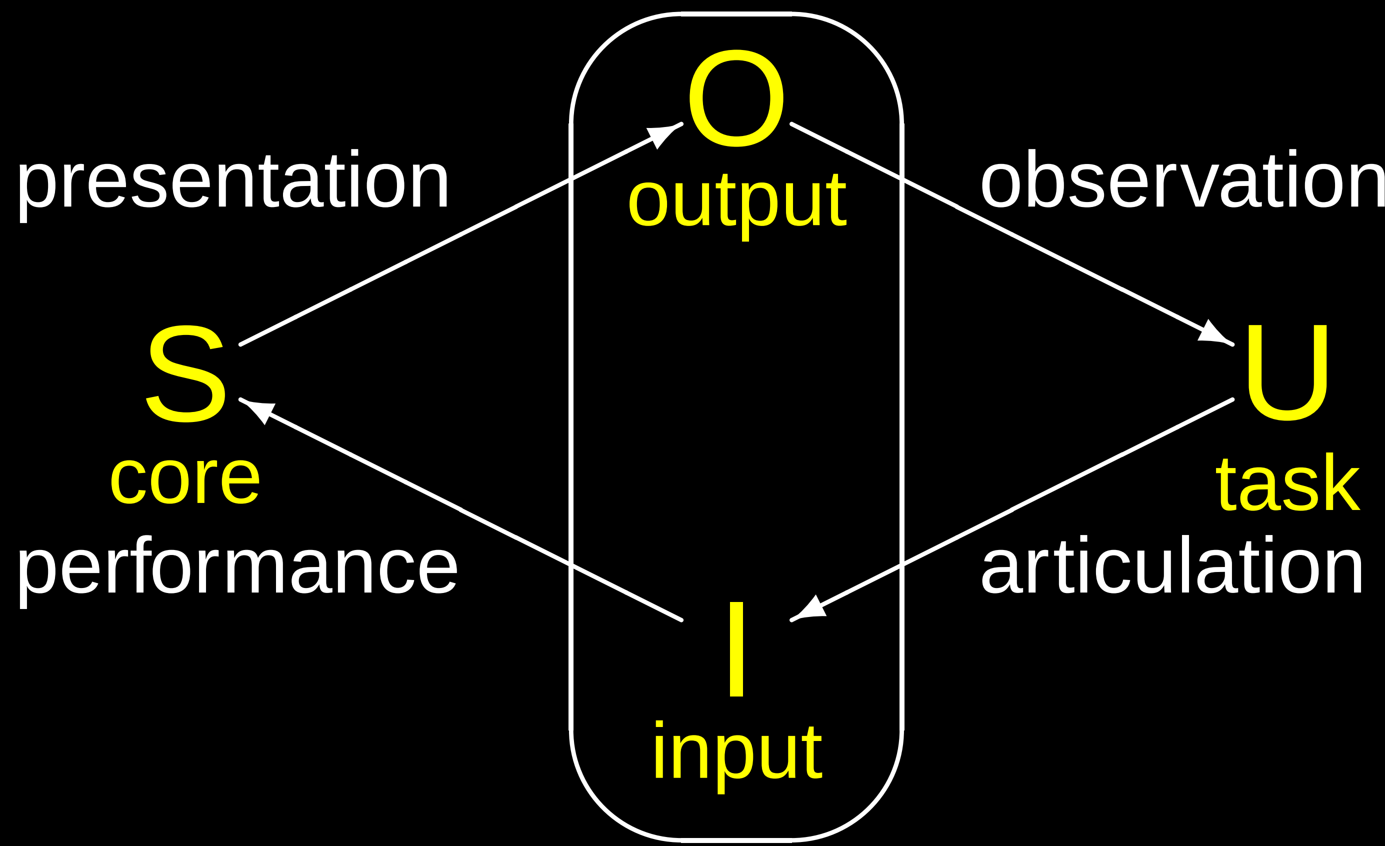
Interaction Framework

the User observes the output and assesses the interaction result wrt the original goal



How easily the User can interpret the output stimuli and evaluate what happened?

Interaction Framework



VCR Example: Interaction

Programming a VCR from a remote control

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All 4 translation may affect the overall interaction

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The user is not sure the VCR is set to record properly $\Longrightarrow$ ineffective interaction

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Presentation Problem: User's interpretation of the output is wrong

How easily the User can interpret the output stimuli and evaluate what happened?

Interaction Context

Other factors that affect the interation context:

- ergonomics, i.e., arrangement of controls and display, surrounding environment, health issues, use of colours
- interaction style, i.e., command line interface, menus, natural language, question/answer and query dialog, form-fills and spreadsheets, WIMP
- social, organisational and legal context, i.e., relationships, feelings and trust among users, motivation, system adequacy, laws and regulations

References

References — Contents

1. General HCI Textbooks
2. General HCI Handbooks
3. Cognitive Psychology Textbooks
4. HCI Websites
5. Books, Papers, Websites on specific topics in
   - Cognitive Psychology
   - Memory
   - Cognitive Models
   - Cognitive Architectures

HCI Textbooks and General

- [Dix et al. 98]
- [Preece et al. 94]
- [Card et al. 83]

[Dix et al. 98]

Alan Dix, Janet Finaly, Gregory Abowd, Russel Beale.
Human-Computer Interaction.
Prentice Hall, 2nd Edition, 1998.

HCI Textbook

One of the most complete general textbooks in HCI, also introduces the use of seveal formal notations, such as Petri nets, CSP, temporal logic, Z. There is now a 3rd edition.
Complementary materials available online at

http://www.acm.org/∼pelman/preece.html

[Preece et al. 94]

Jenny Preece, Yvonne Rogers, Helen Sharp, David Benyon, Simon Holland and Tom Carey. *Human-Computer Interaction*. Addison Wesley, 1994.

HCI Textbook

The first HCI textbook to contain all pedagogical features (examples, exercises, etc.). Now a bit old. Book review available online at

http://www.acm.org/∼perlman/preece.html

[Card et al. 83]

Stuart K. Card, Thomas P. Moran and Allen Newell.
The Psychology of Human-Computer interaction.
Lawrence Erbaum Associates, 1983.

HCI General Book

Classical book that defines the early theoretical basis of HCI from an Information Processing perspective. Develops and describes the Model Human Processor in details.

HCI Handbooks

- [Baecker et al. 87]
- [Baecker et al. 95]
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