Perceptual Capacities and Constraints in Augmented Reality and Virtual Reality

Lecture on AR/VR Interaction and Spatial Reasoning: Prof Roy Eagleson   eagleson@uwo.ca

Workshop Organizers: Roy Eagleson   and   Georges Hattab

Keynote Speakers: Ulrich Eck / Nassir Navab and Bernhard Preim

Workshop Sponsor: Intuitive Surgical

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In "Perceptual Capacities and Constraints in AR/VR for the visualization of 3D Medical image data"

Workshop at Computer-Assisted Radiology and Surgery Conference, Eagleson and Hattab, Rennes, June 18.

JUNE 17-21, 2019 @ RENNES, FRANCE

Computer Assisted Radiology and Surgery

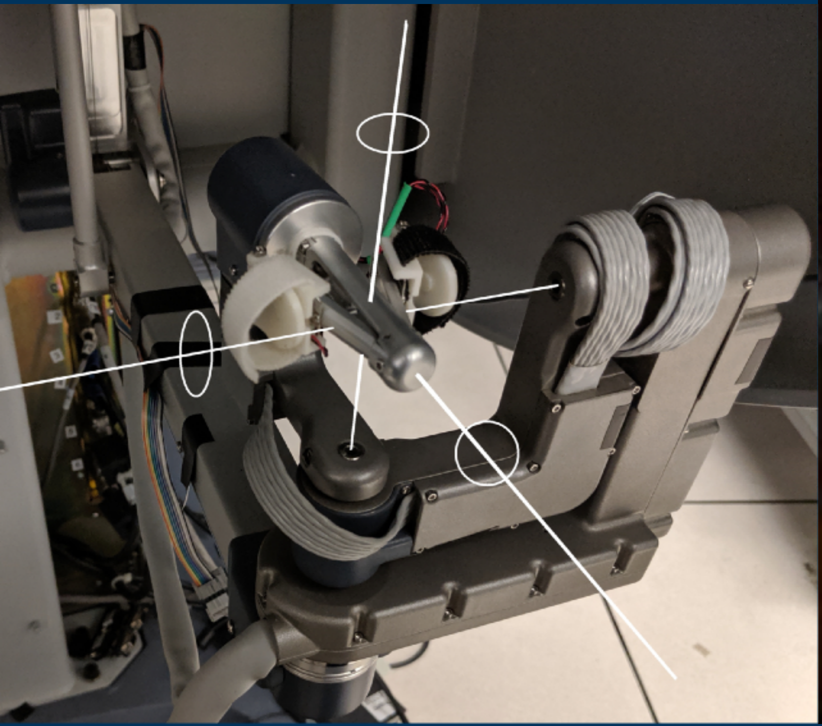
CARS 2019

Perceptual Capacities and Constraints

[in AR/VR] [for Medical Applications]

- Tutorial Introduction to this workshop:

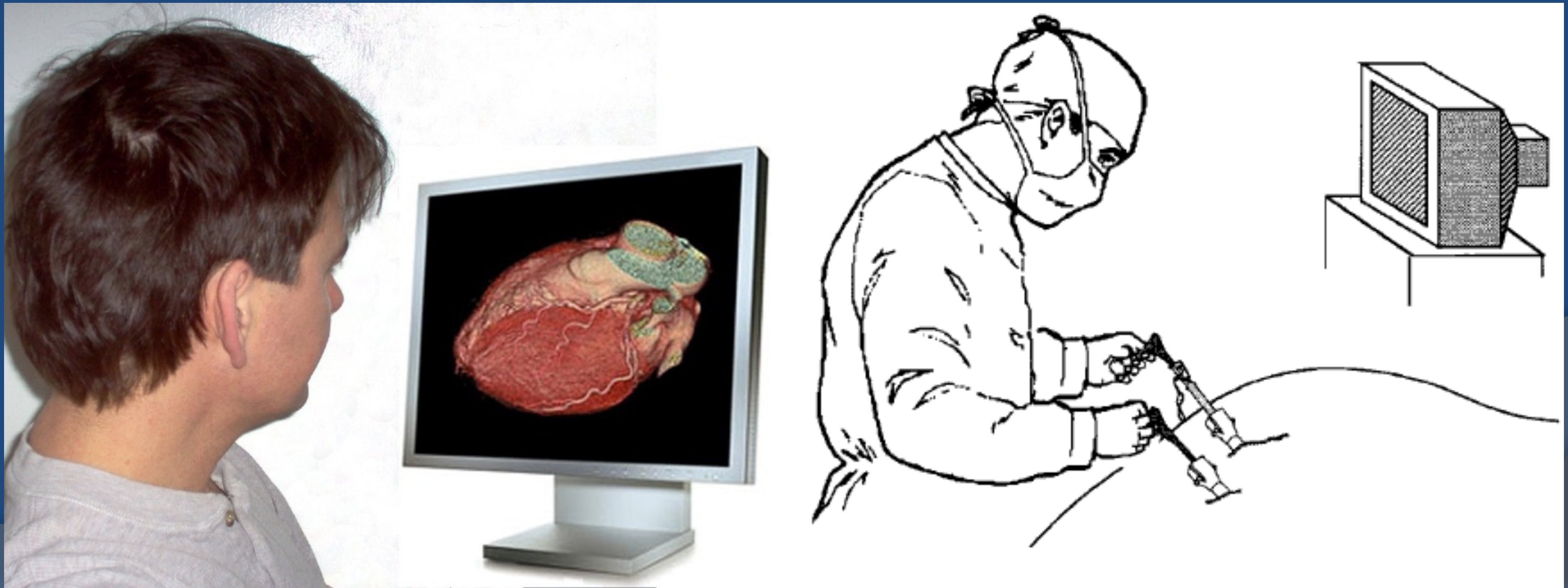
- Perception (perception of entities and spatial relations)
- Action (sensori-motor interaction)
- Cognition (task-level constraints)



Mimic Technologies MSim™ software for the dV-Trainer robotic surgery simulator

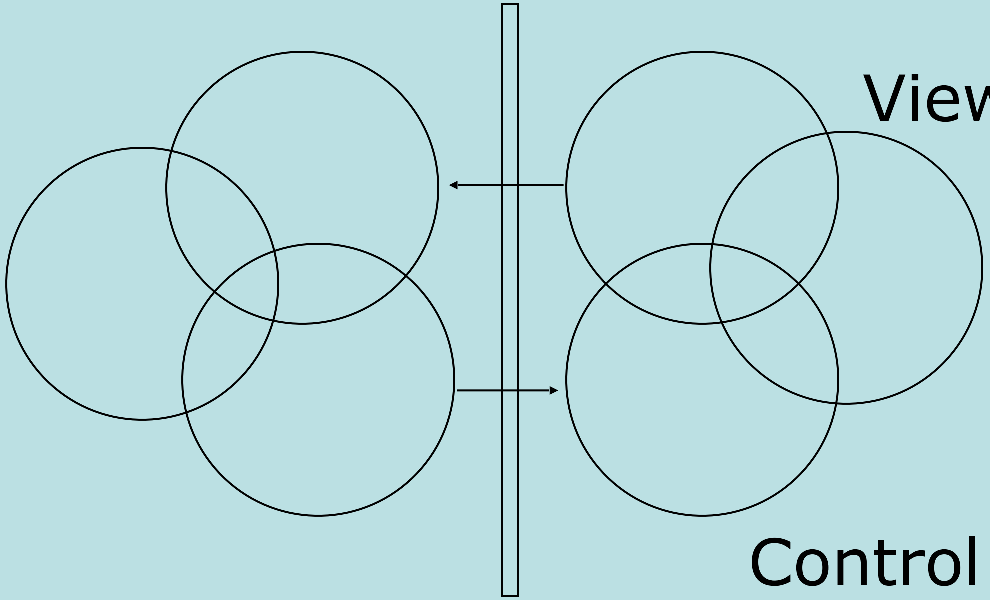
Capacities of the Human in the System
(+) Perception
(+) Action
(+) Cognition

Constraints and Limitations:
(-) Perception is effortless; but not cognitively penetrable
[training and expertise cannot overcome perceptual/motor illusions]



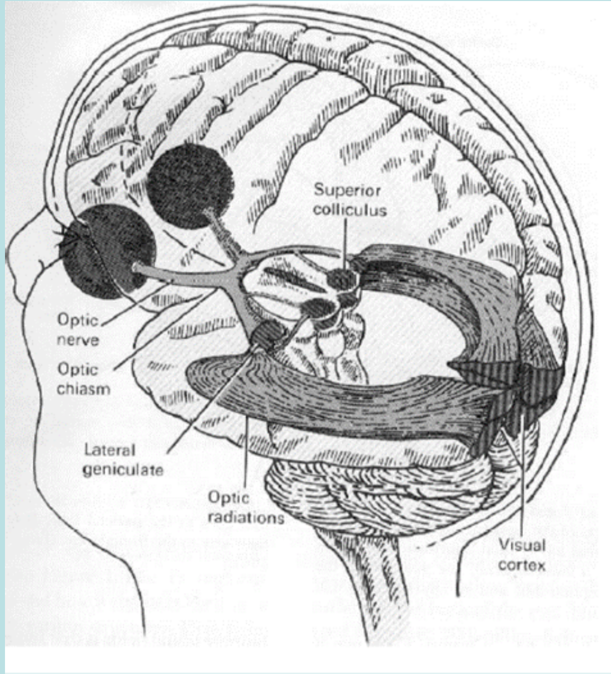
Talk overview (v.2) Human-Computer Interfaces:

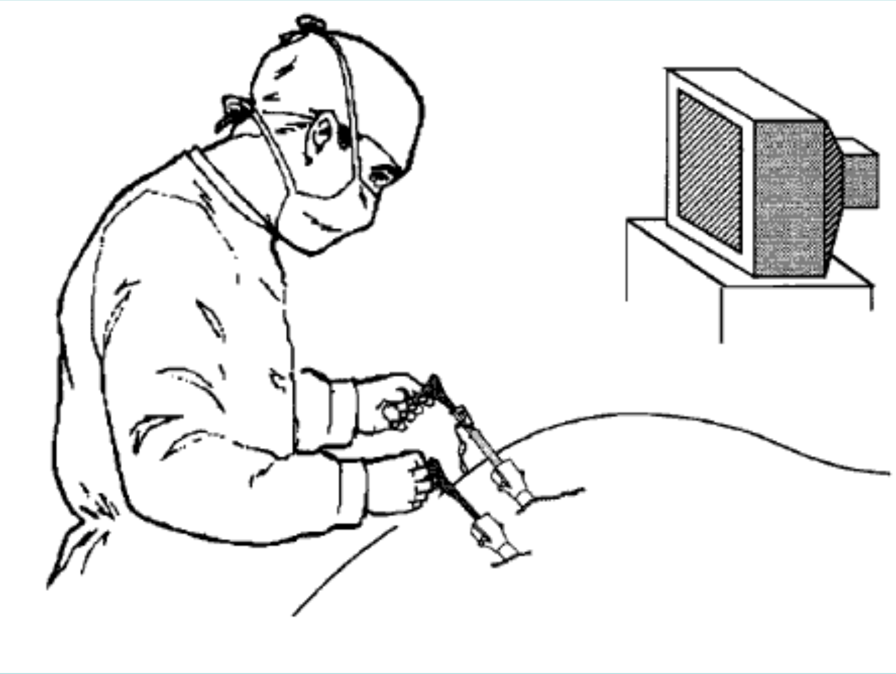
Perception — View (+haptics)

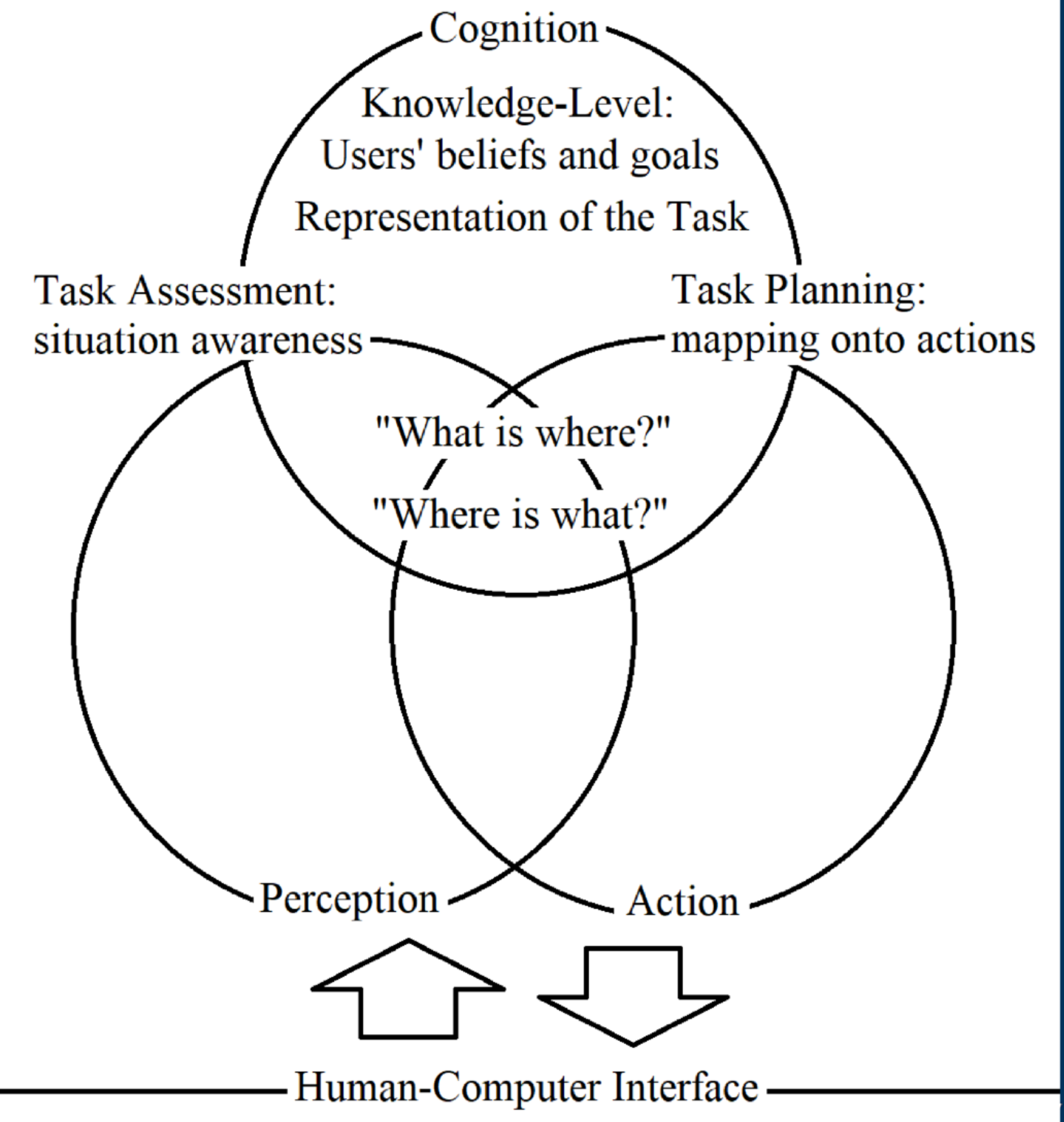


Cognition — Model

Action — Control







[human factors]

Perception / Cognition / Action

[in AR/VR]
[for Medical Applications]

from,
Roy Eagleson and Sandrine de Ribaupierre (2019) "Human-Machine Interfaces for Medical Imaging and Clinical Interventions“ Chapter in "Handbook of Medical Image Computing and Computer Assisted Intervention". Zhou, Rueckert, and Fichtinger, Eds. Academic Press.

Perceptual Capacities and Constraints

Special Capacities:

Rapid bottom-up processing. (effortless, no cognition)

Surprising Constraints:

Prone to errors (illusions) if cues are inconsistent or ambiguous

Perceptual channels provide Relative Depth (not absolute)

→Spatial Relations implicate ‘spatial reasoning’

→ this implicates Cognition’s role (effortful: cognitive load)

Perception / Cognition / Action

And, what outcome from Perception and Cognition?

The outputs from humans: Motor outputs – ‘action’
Are the inputs to computer interfaces (or machine interfaces)

Perception / Cognition / Action

Motor outputs: ‘action’

- Movement in free space (or with path constraints)
- Movement along, against, or with an object or surface

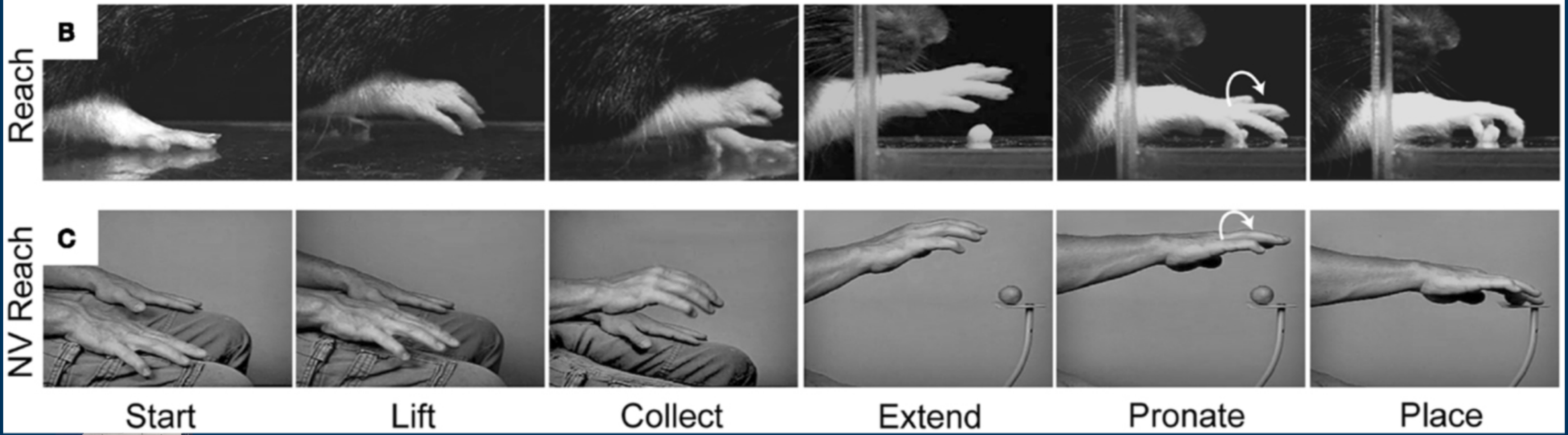
- Commonly called “navigation” vs “interaction”

- interaction: ‘inter’ action, between two objects

Perception / Cognition / Action

Motor outputs: ‘action’

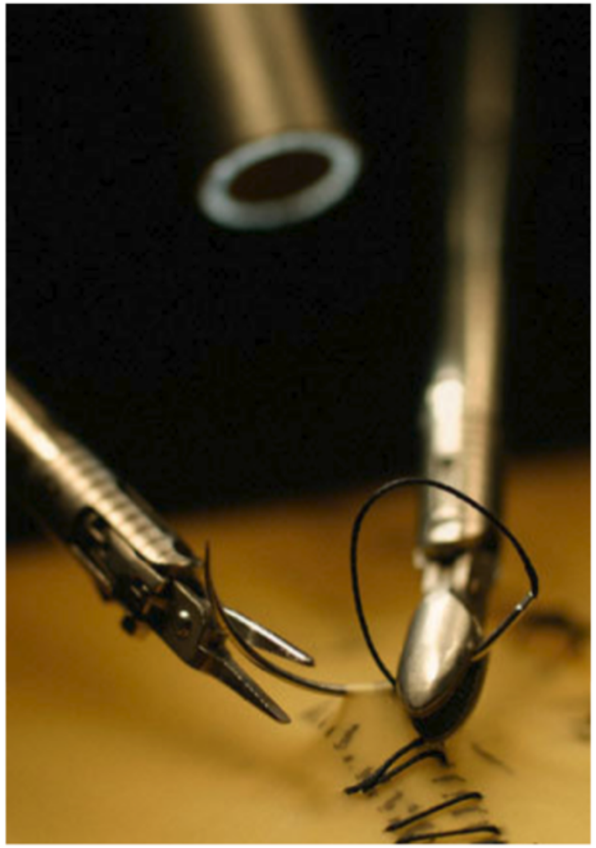
Navigation and Manipulation: “Reaching and Grasping”



Perception / Cognition / Action

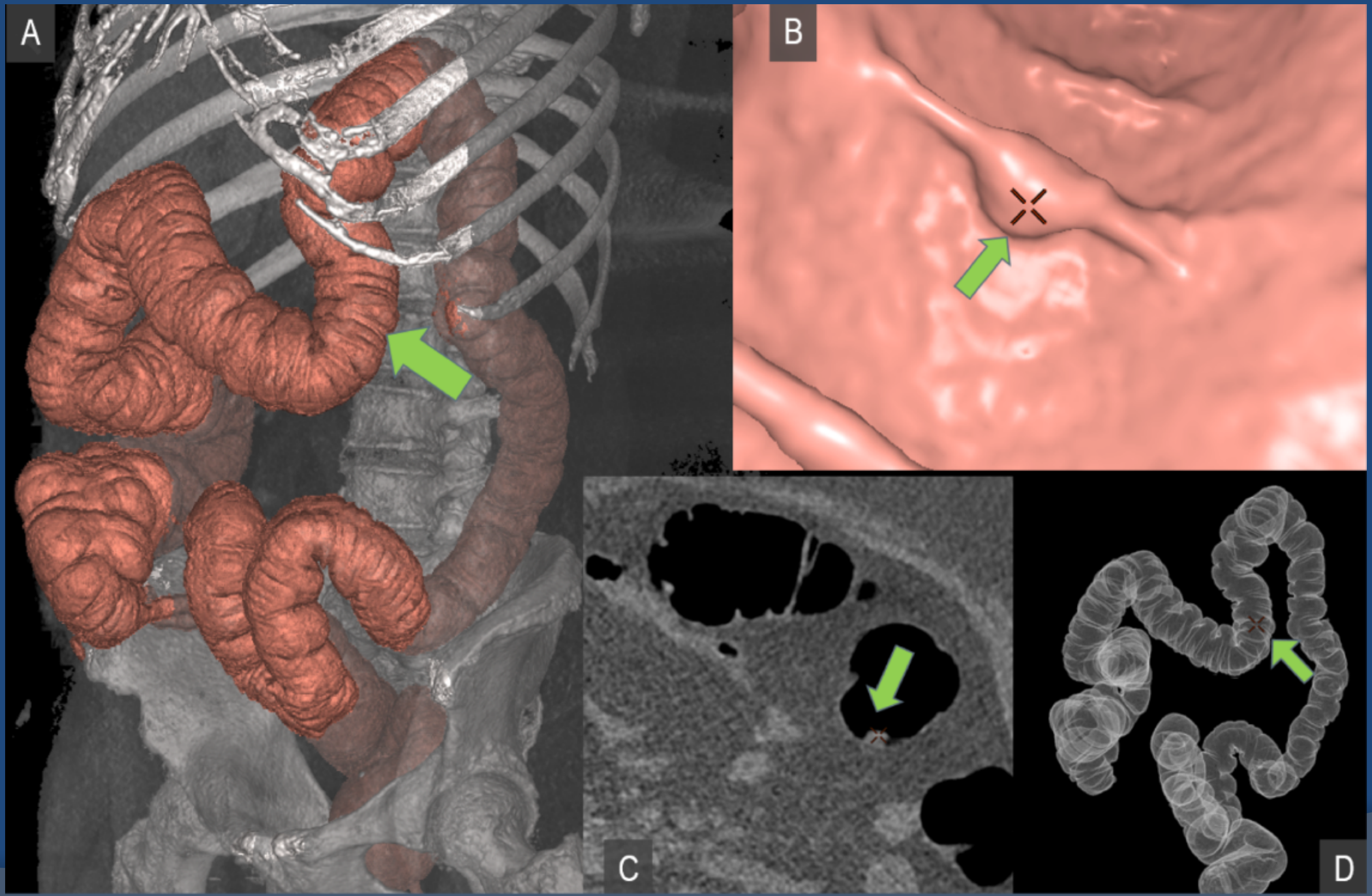
Motor outputs: ‘action’

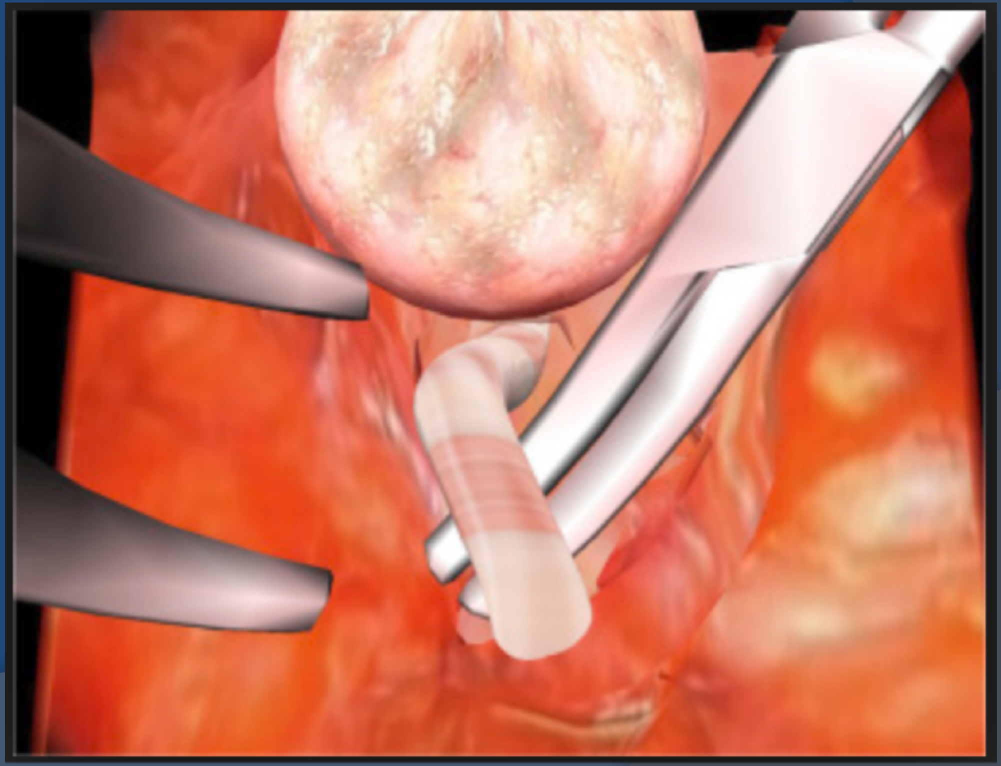
Perception / Cognition / Action



- interaction: ‘inter’ action, between two objects

Navigation vs Manipulation





Thank you for citing the following material as,

Roy Eagleson and Sandrine de Ribaupierre (2018)
"Visual Perception and Human–Computer Interaction in Surgical Augmented and Virtual Reality Environments"
Chapter in "Mixed and Augmented Reality in Medicine",
Peters, Linte, Yaniv, and Williams, Eds. CRC Press. pp. 83-98.

Perceptual Capacities and Constraints

Special Capacities: “Perceptual Channels”

Rapid bottom-up processing. (effortless, no cognition)

- Shape from contour
- Shape from shading
- Shape from motion (and depth from motion)
- Shape from stereo (relative depth from stereo)
    - relative depth from translucency
    - relative depth from texture and size (cognitive)

Perceptual Capacities and Constraints

Special Capacities:

Rapid bottom-up processing. (effortless, no cognition)

Surprising Constraints:

Prone to errors (illusions) if cues are inconsistent or ambiguous

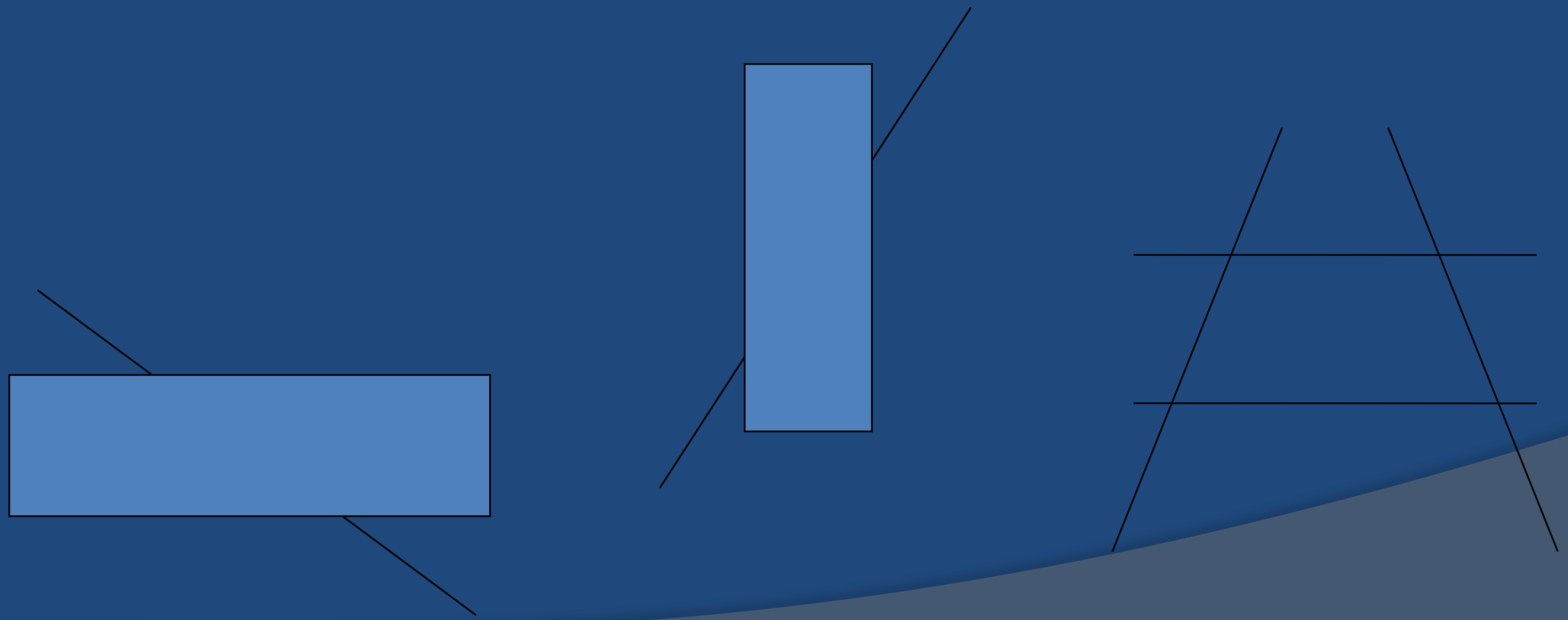
Perceptual channels provide Relative Depth (not absolute)

→Spatial Relations implicate 'spatial reasoning'

→ this implicates Cognition's role (effortful: cognitive load)

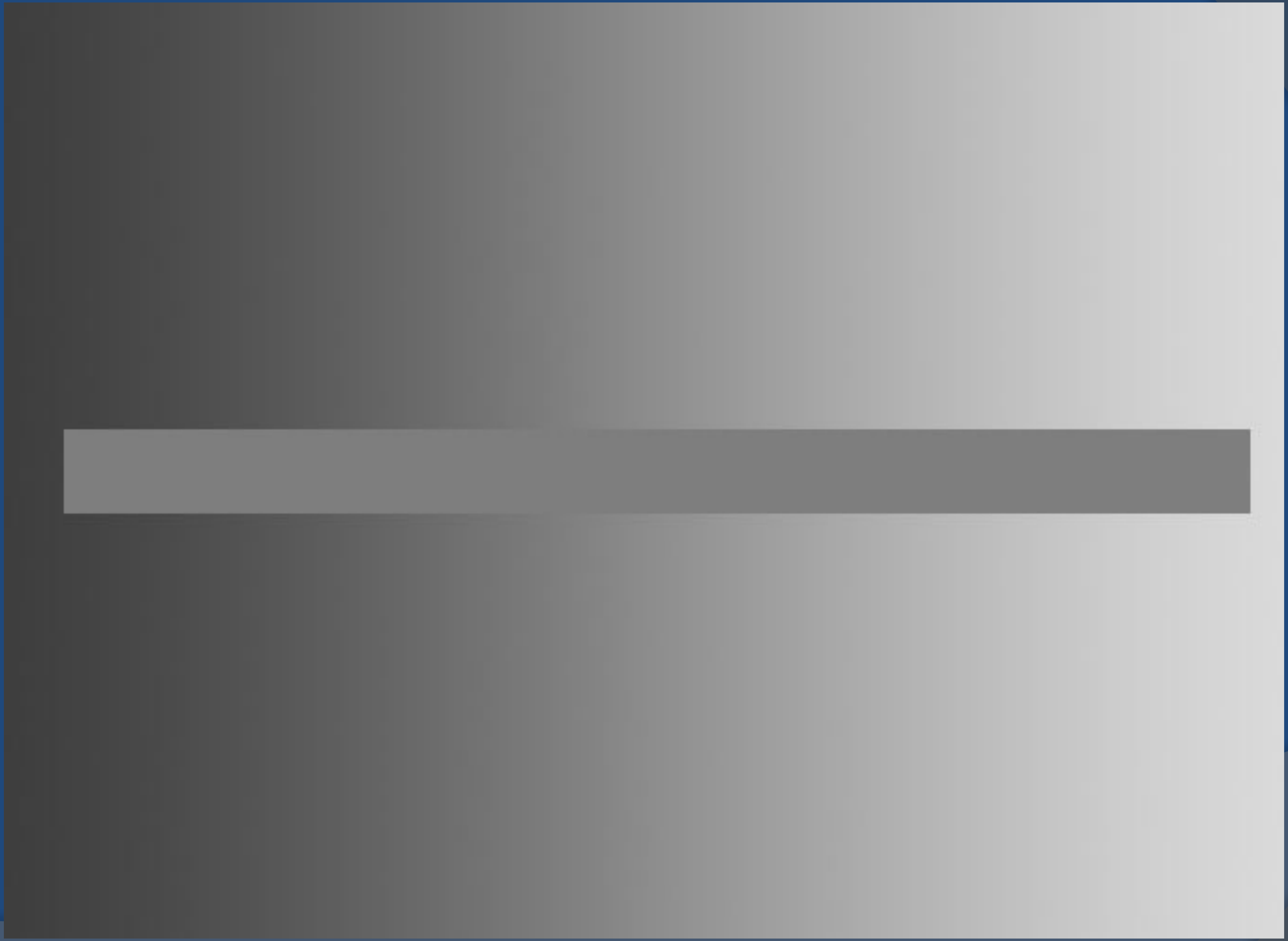
Capacities and Constraints of Human Perception

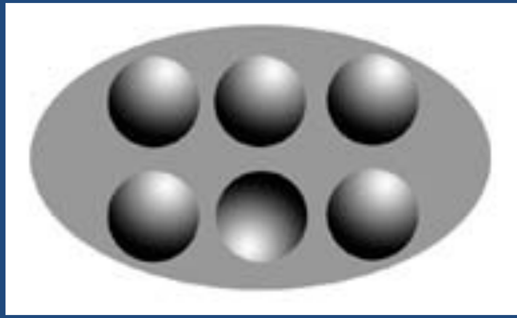
(-) Perceptual system makes ‘natural world’ assumptions
(-) Visual Cognition (‘top-down perception’) is effortful and task-specific
(-) Actions are controlled by a nested hierarchy: sensory-motor control, impenetrably constrained at a low level, is modulated from above by the cognitive system.

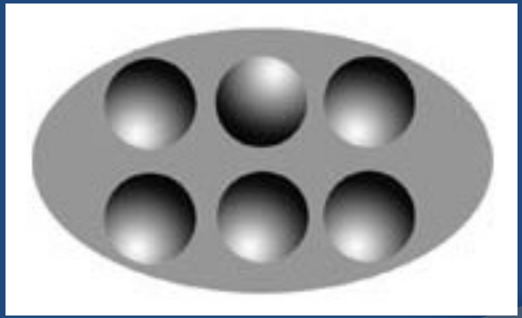


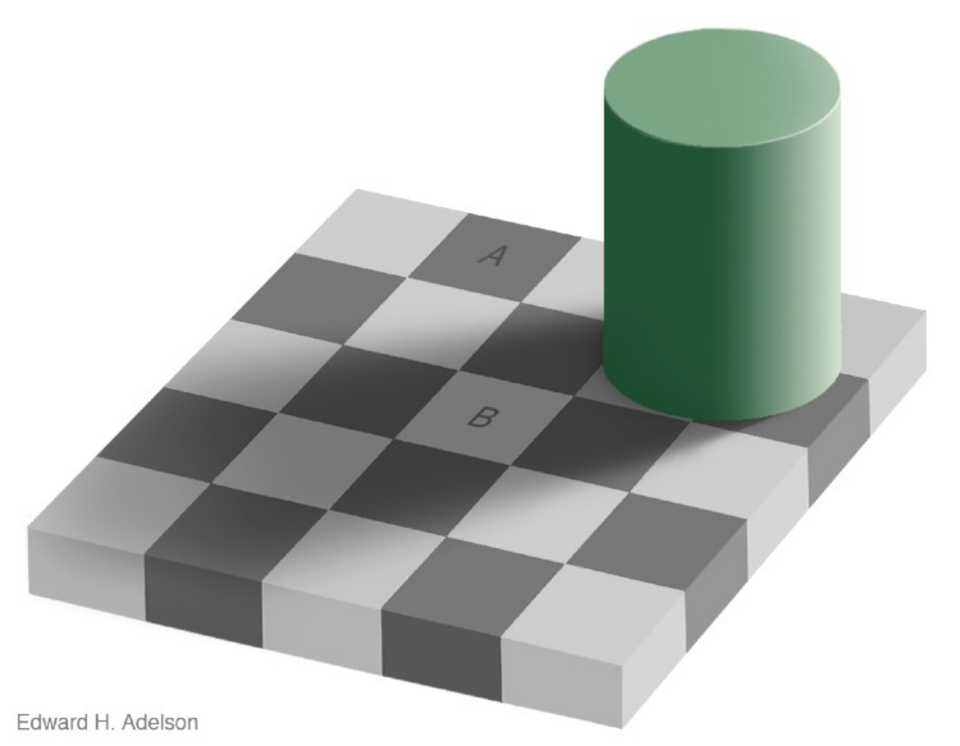
Baker Street Tube Tunnel

Colonoscopy tube tunnel





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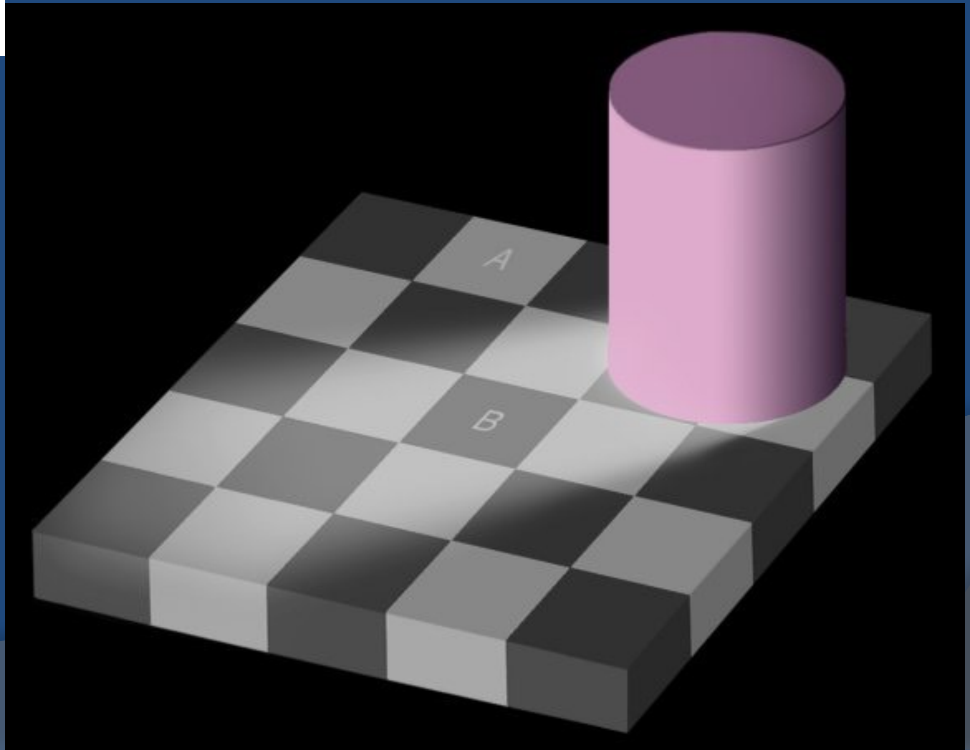
Edward H. Adelson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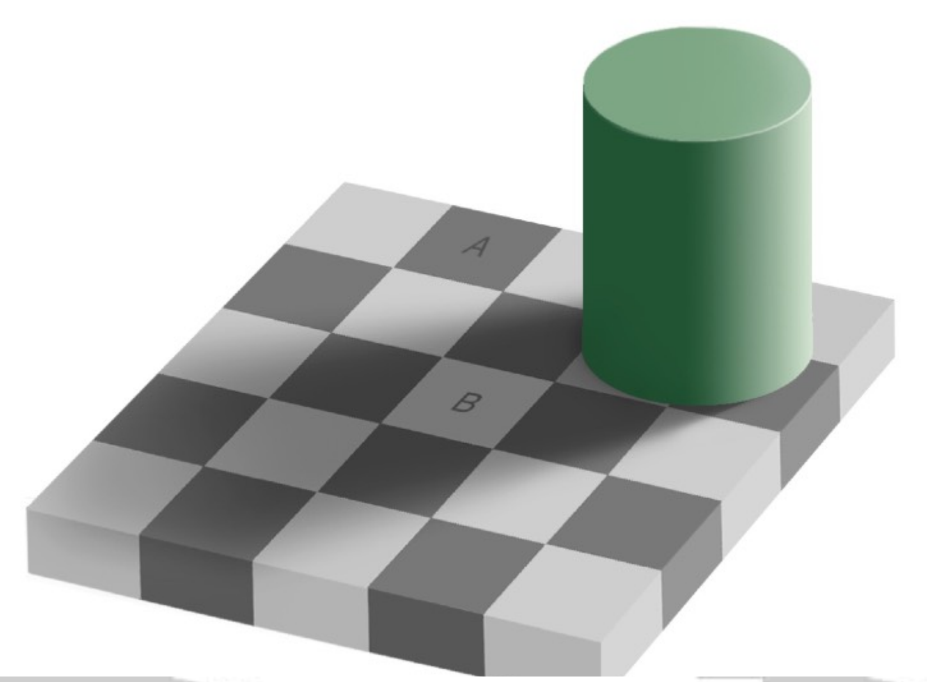
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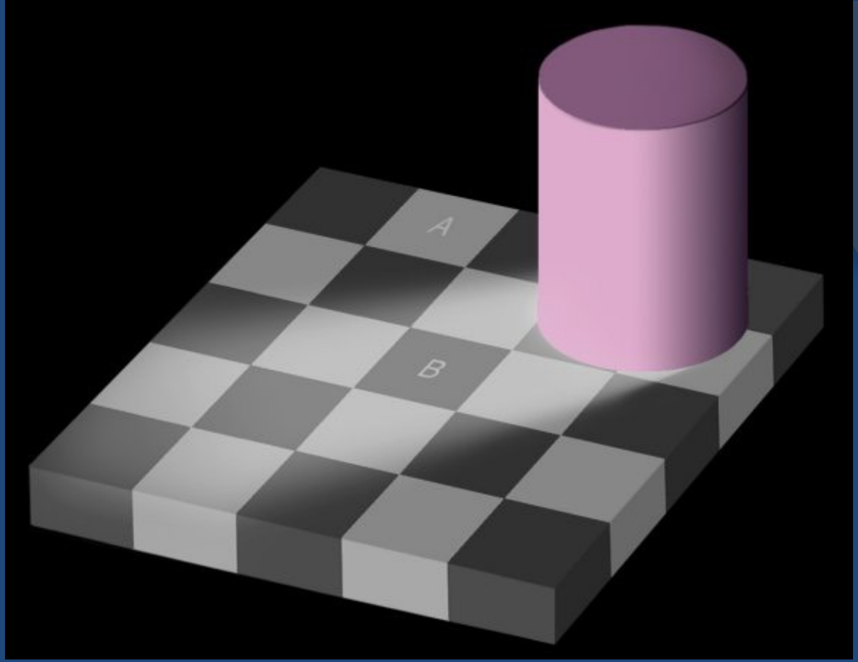
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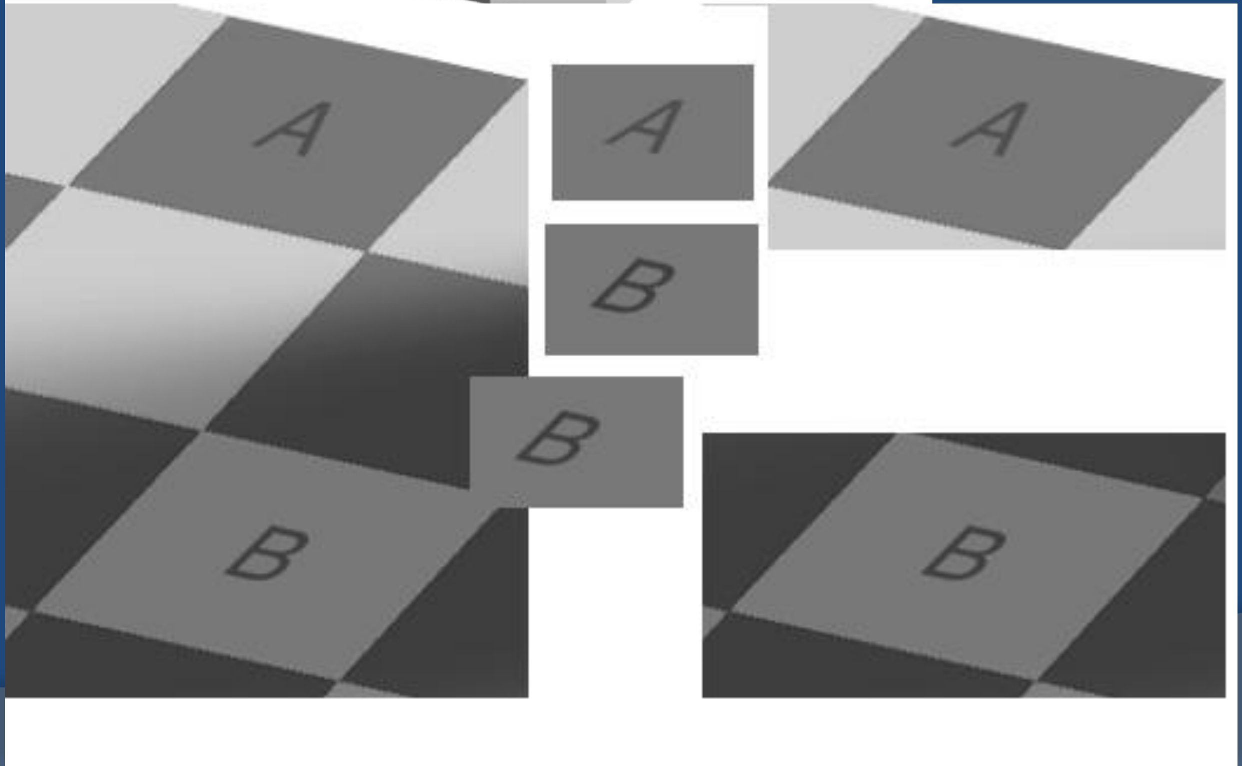
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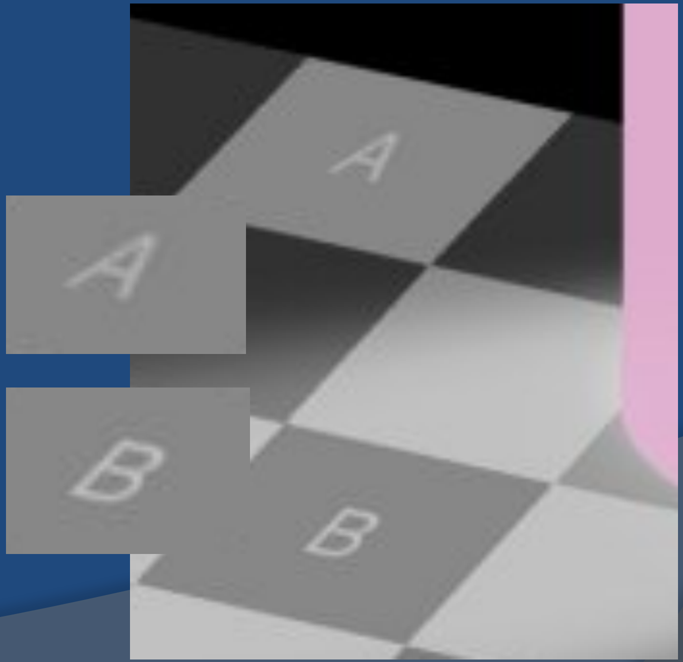
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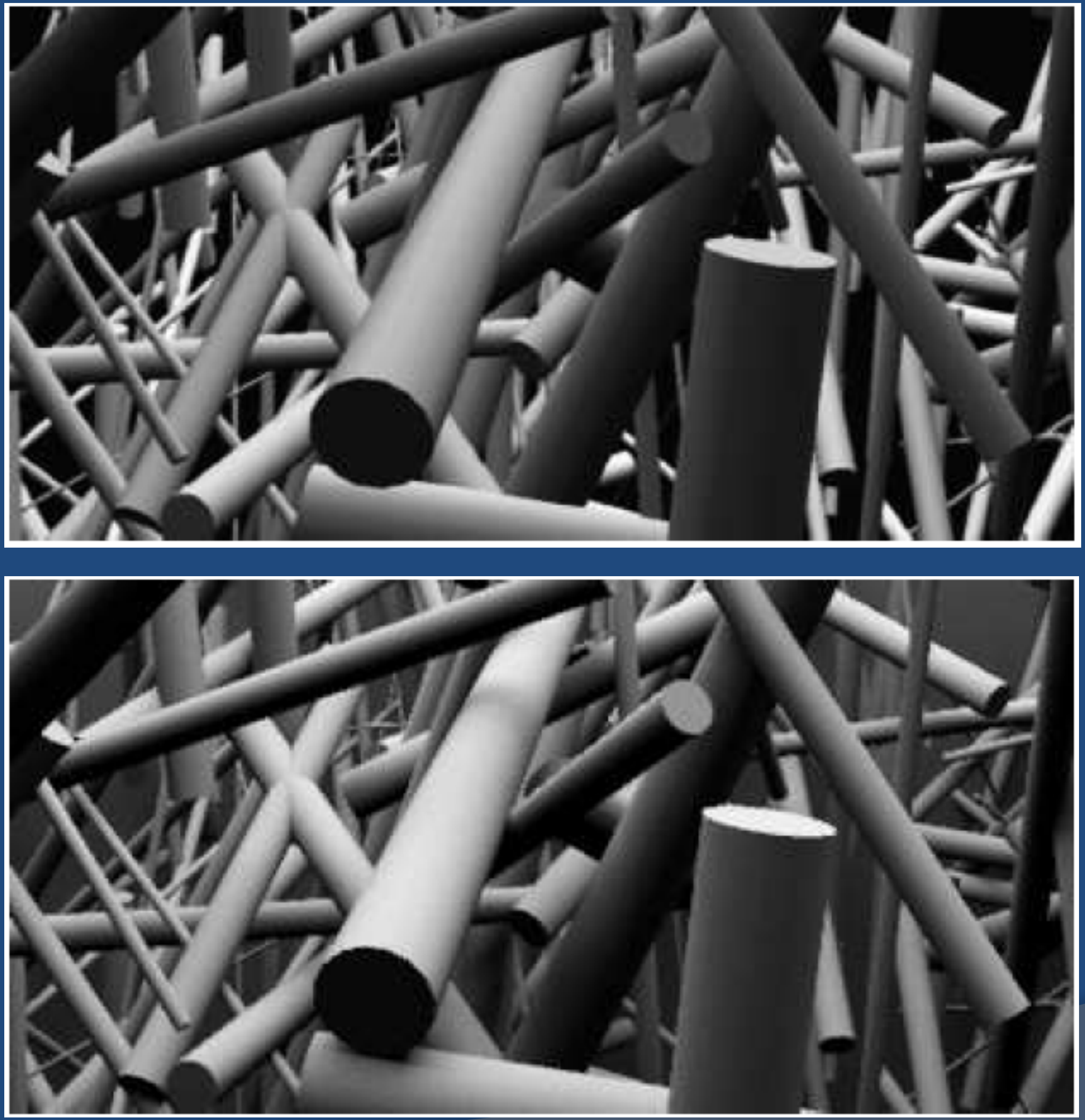
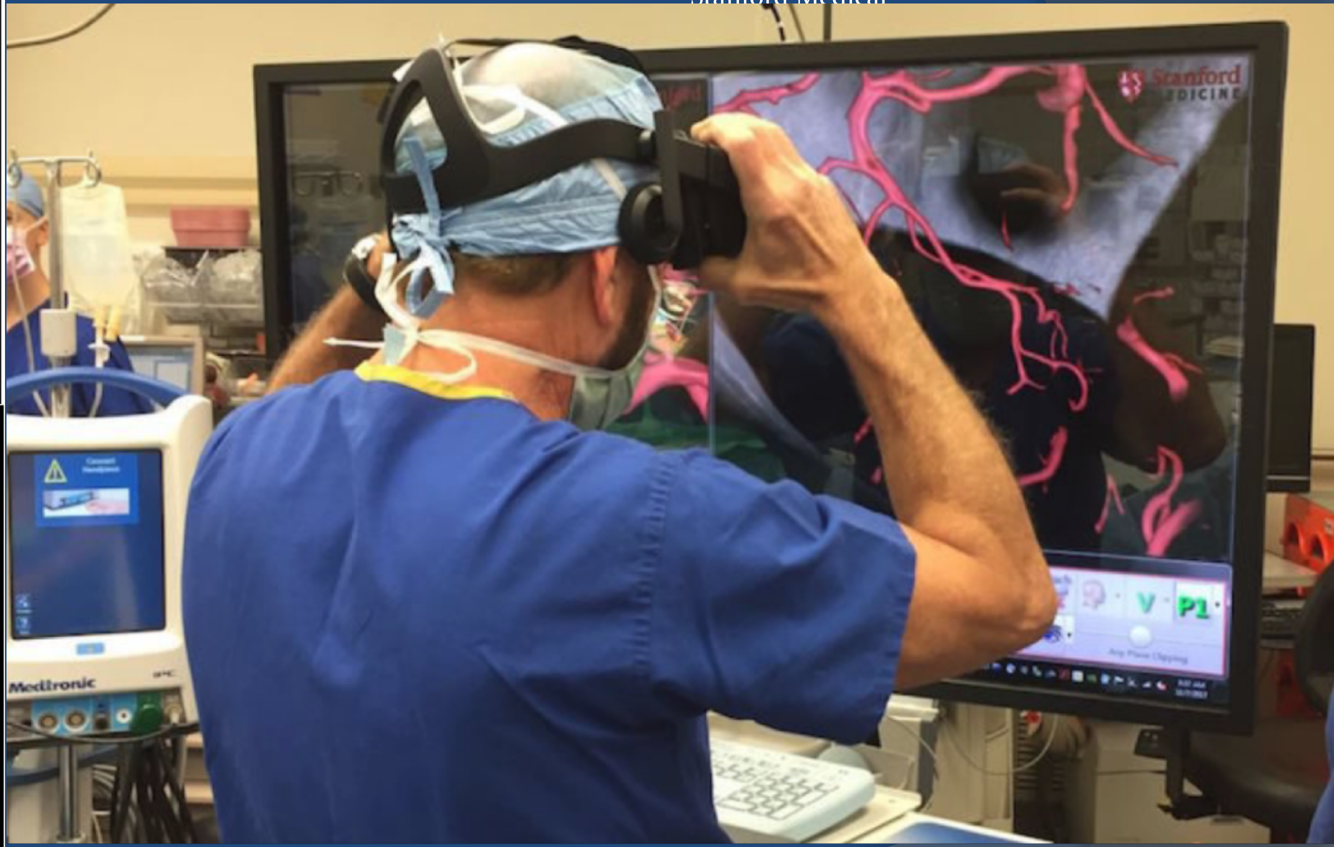
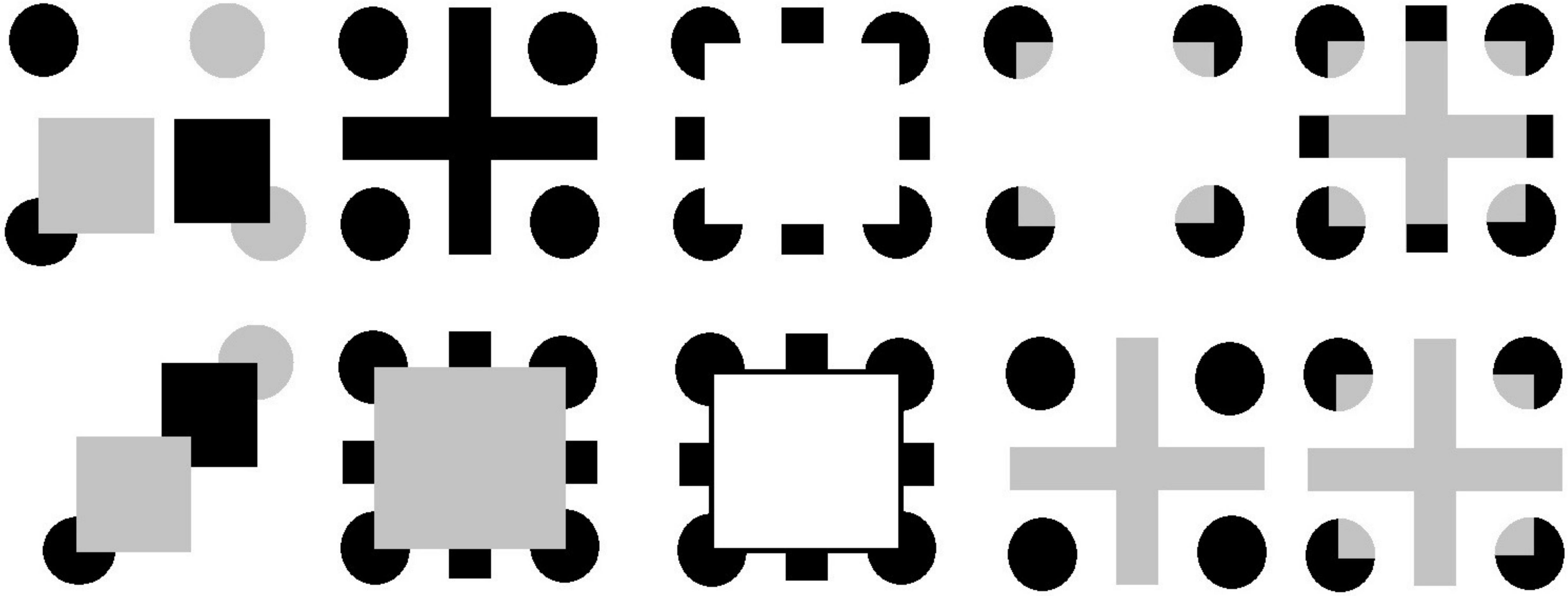


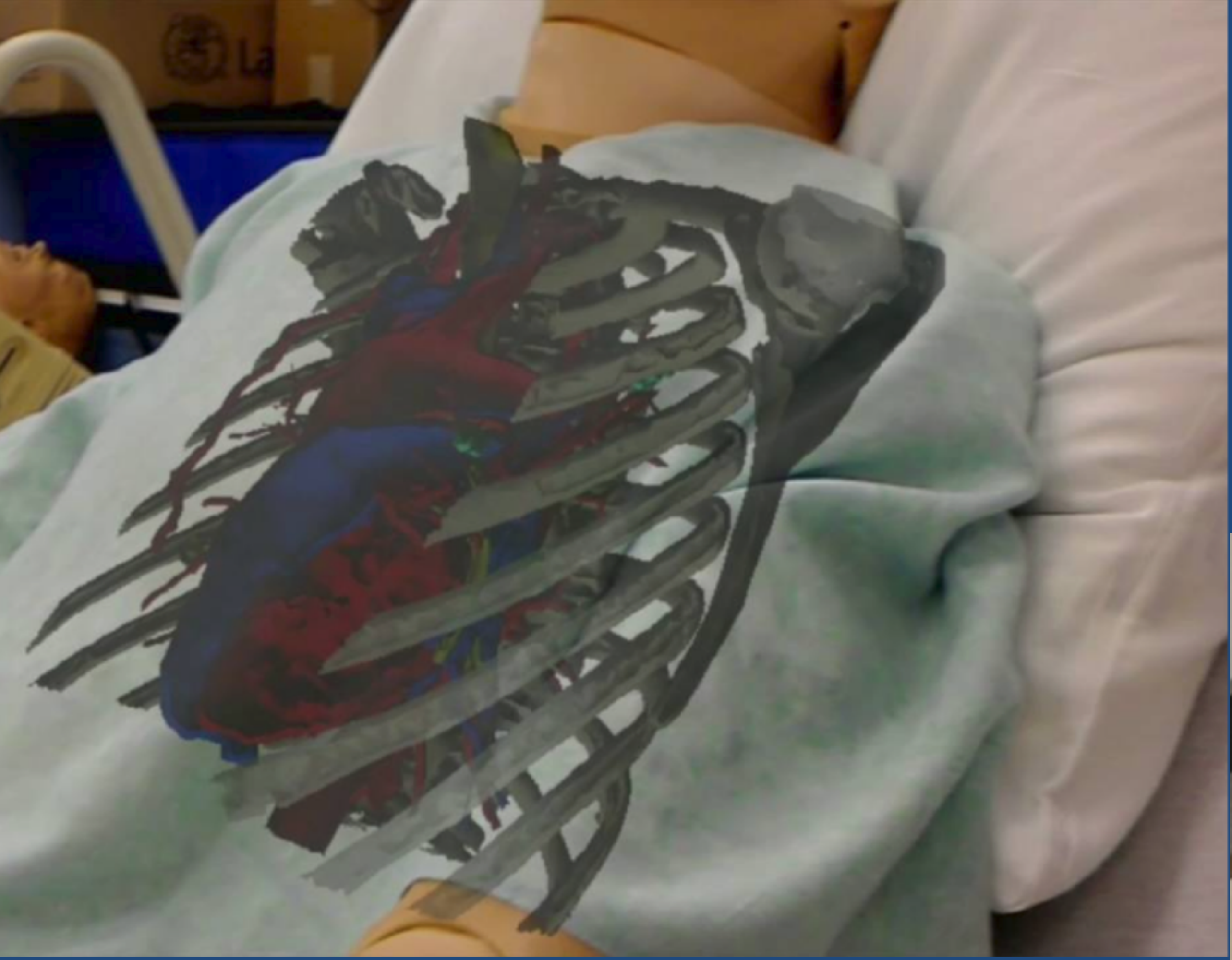
Banks and Westin (2008) Visualization in Medicine and Life Sciences

Abhari, Peters, de Ribaupierre, Eagleson, 2011

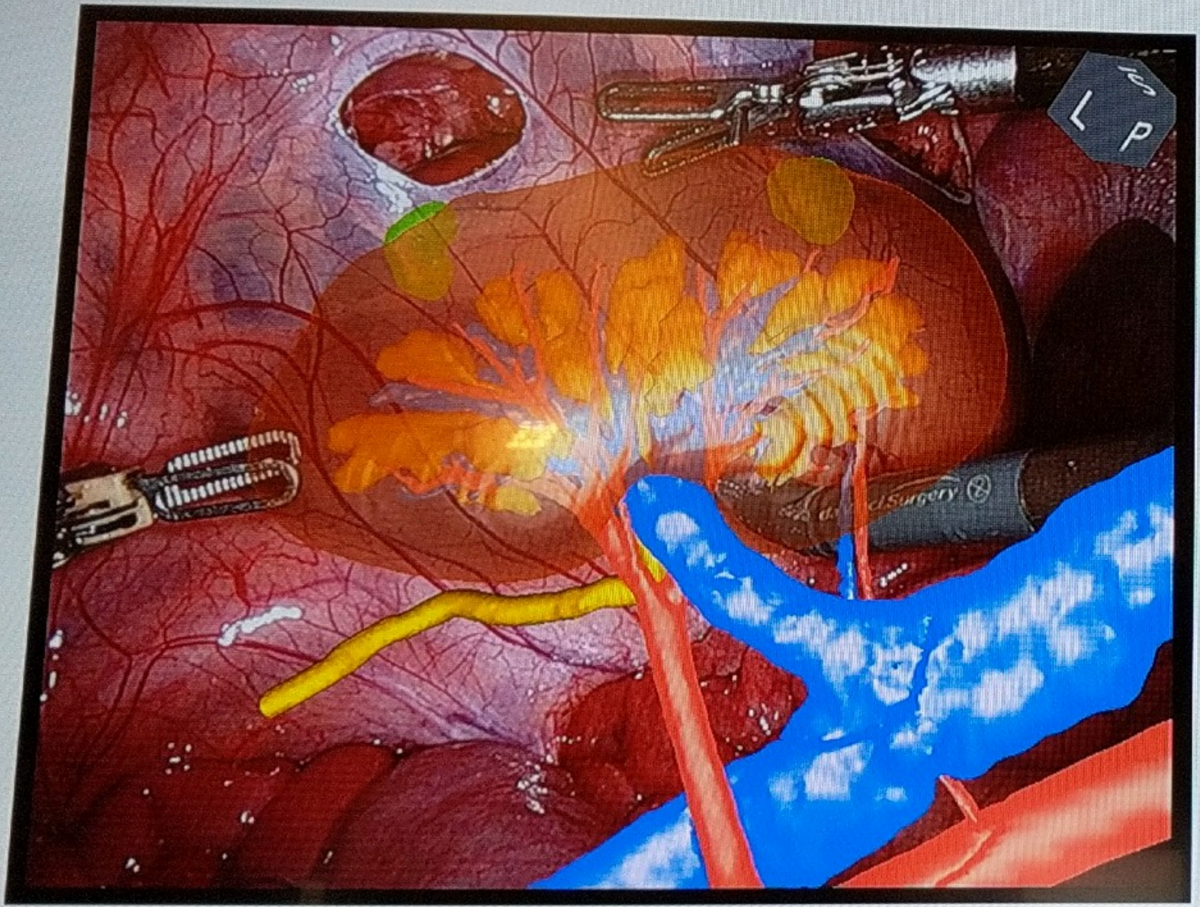
Stanford Medical

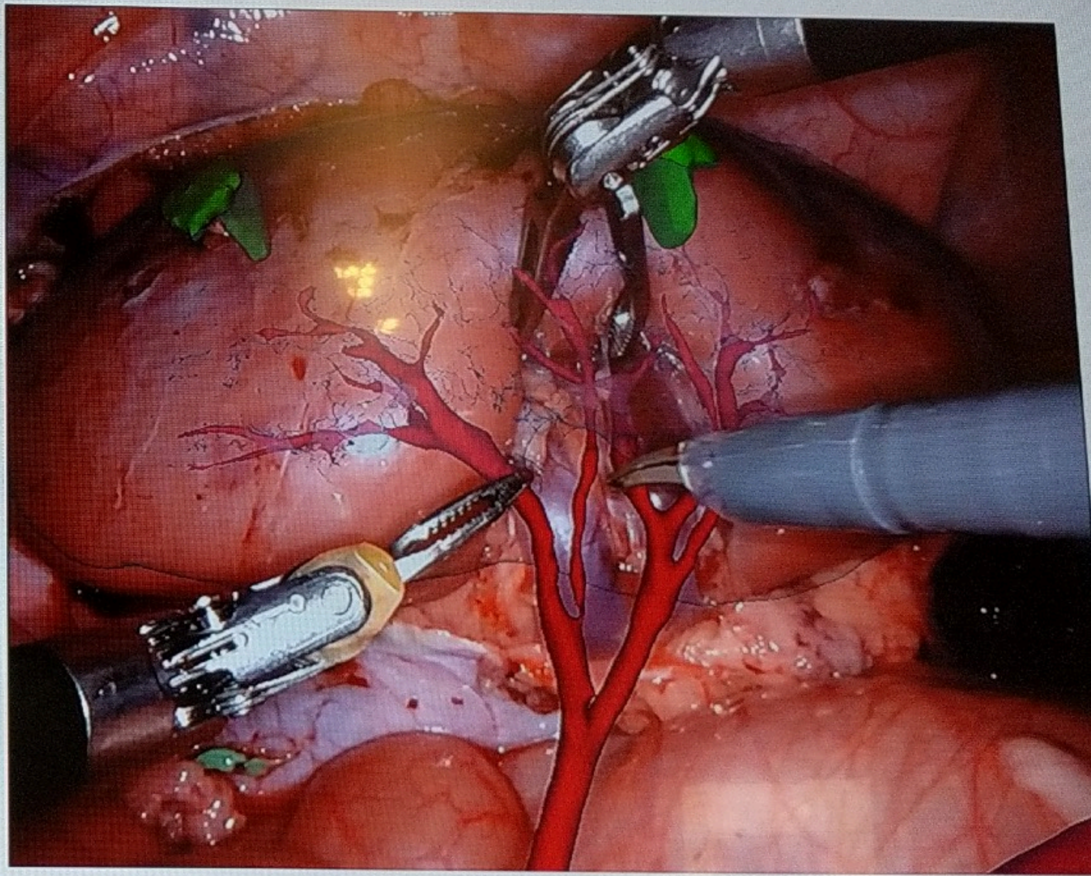






Surgical Scene Perception: Spatial





This technology is still in development, not CE Marked nor 510(k) cleared, and not for sale. The safety and effectiveness of this technology has not been established.

Previous, and following material are from,

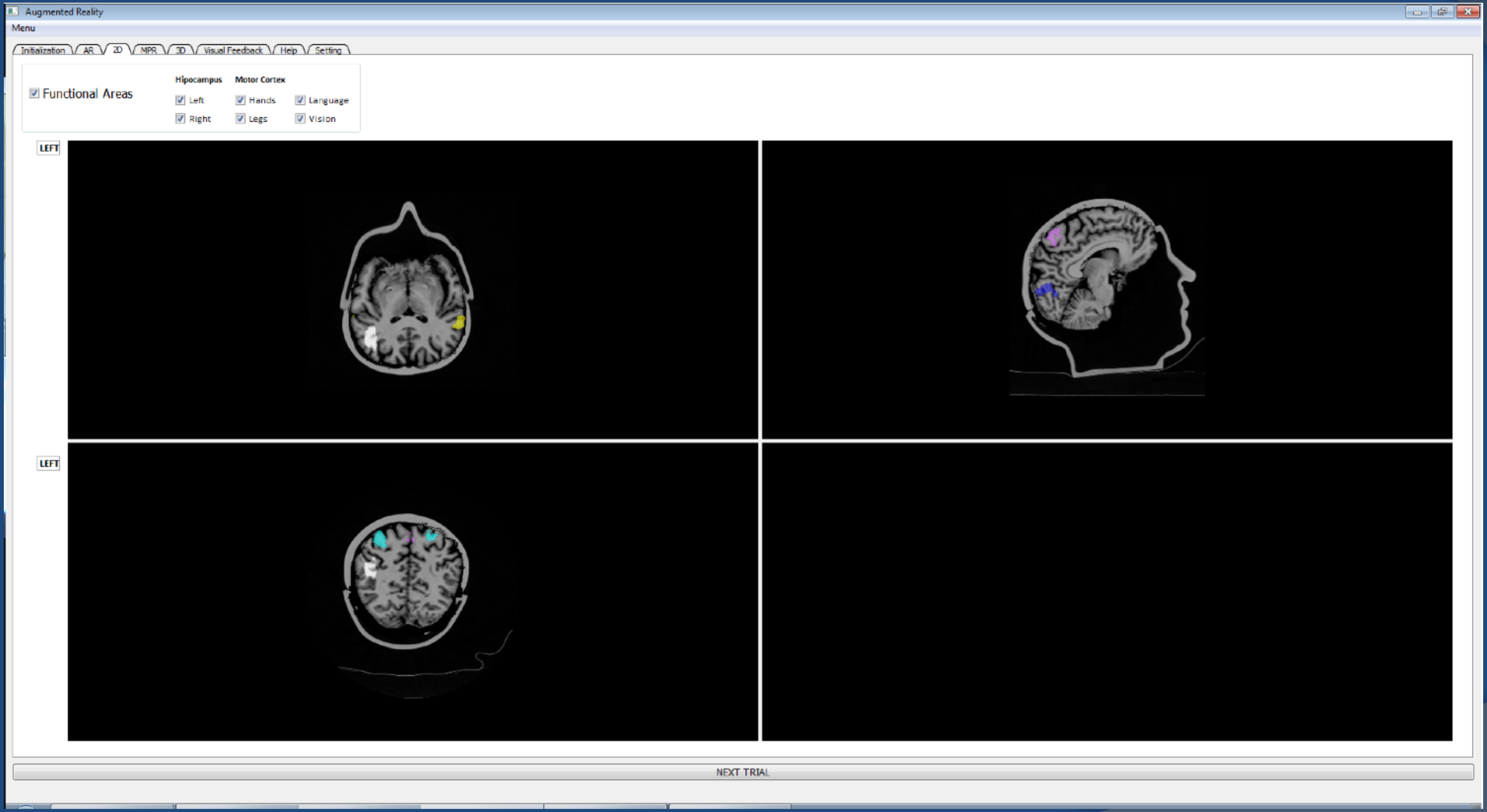
Kramers,M, Armstrong,R, Bakhshmand,S, Fenster,A, de Ribaupierre,S, Eagleson,Roy (2014) "Evaluation of a mobile augmented reality application for image guidance of neurosurgical interventions“ MMVR: Medicine Meets Virtual Reality, pp.204-208.

Abhari,K, Baxter,J, Chen,E, Khan,A, Wedlake,C, Peters,T, Eagleson,R, de Ribaupierre,S (2013) "The role of augmented reality in training the planning of brain tumor resection" in "Augmented reality environments for medical imaging and computer-assisted interventions", Linte, et. al. Eds. pp. 241-248

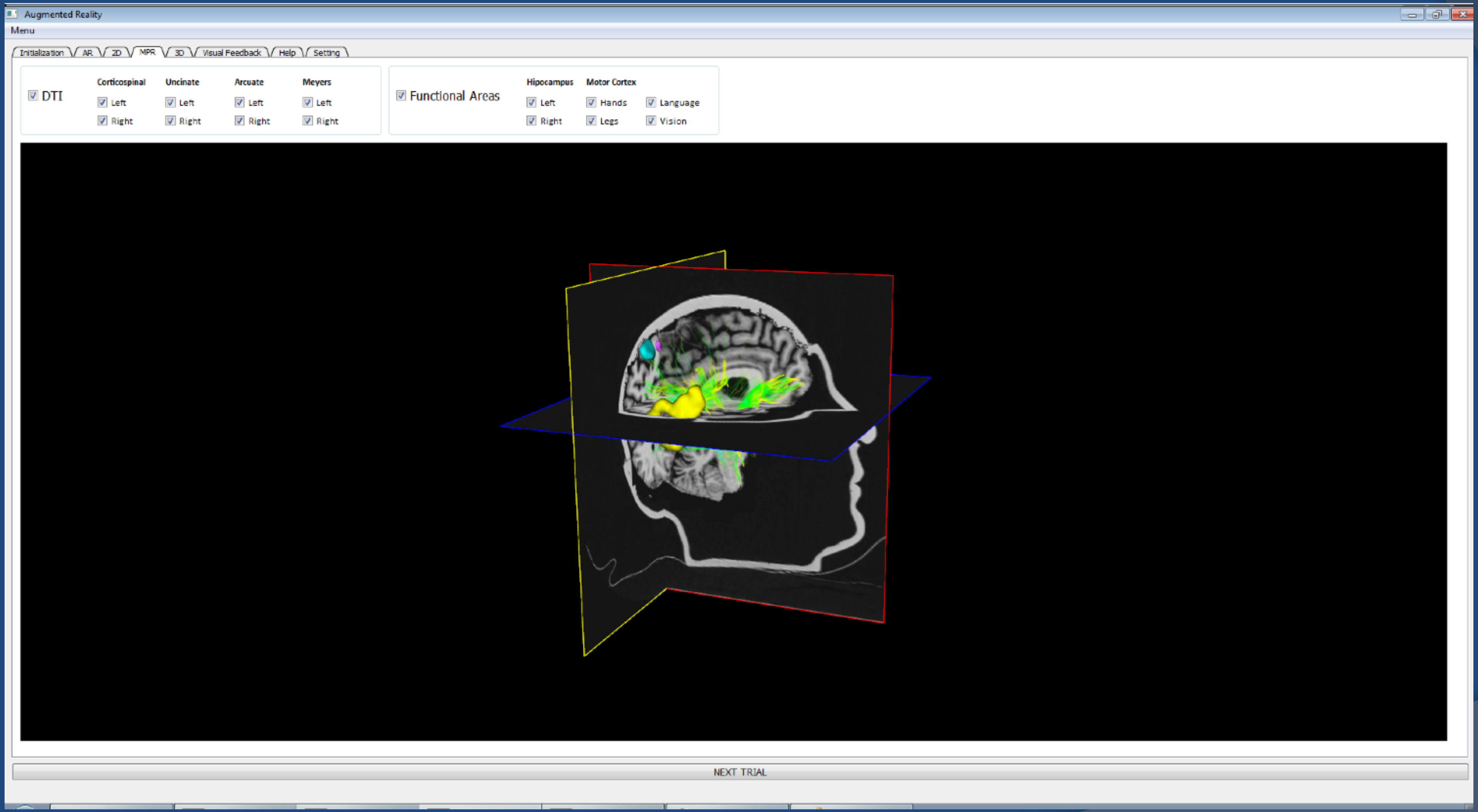
Evaluation of Perceptual and Spatial Reasoning Skills in Surgical Training:

- Tumour resection planning
- (Kamyar Abhari, TP, SdR, RE)
- Task Analysis: Insertion point selection, Angle of approach, Avoidance of eloquent areas.
- What Visualization Modality is optimal for each phase of the task?

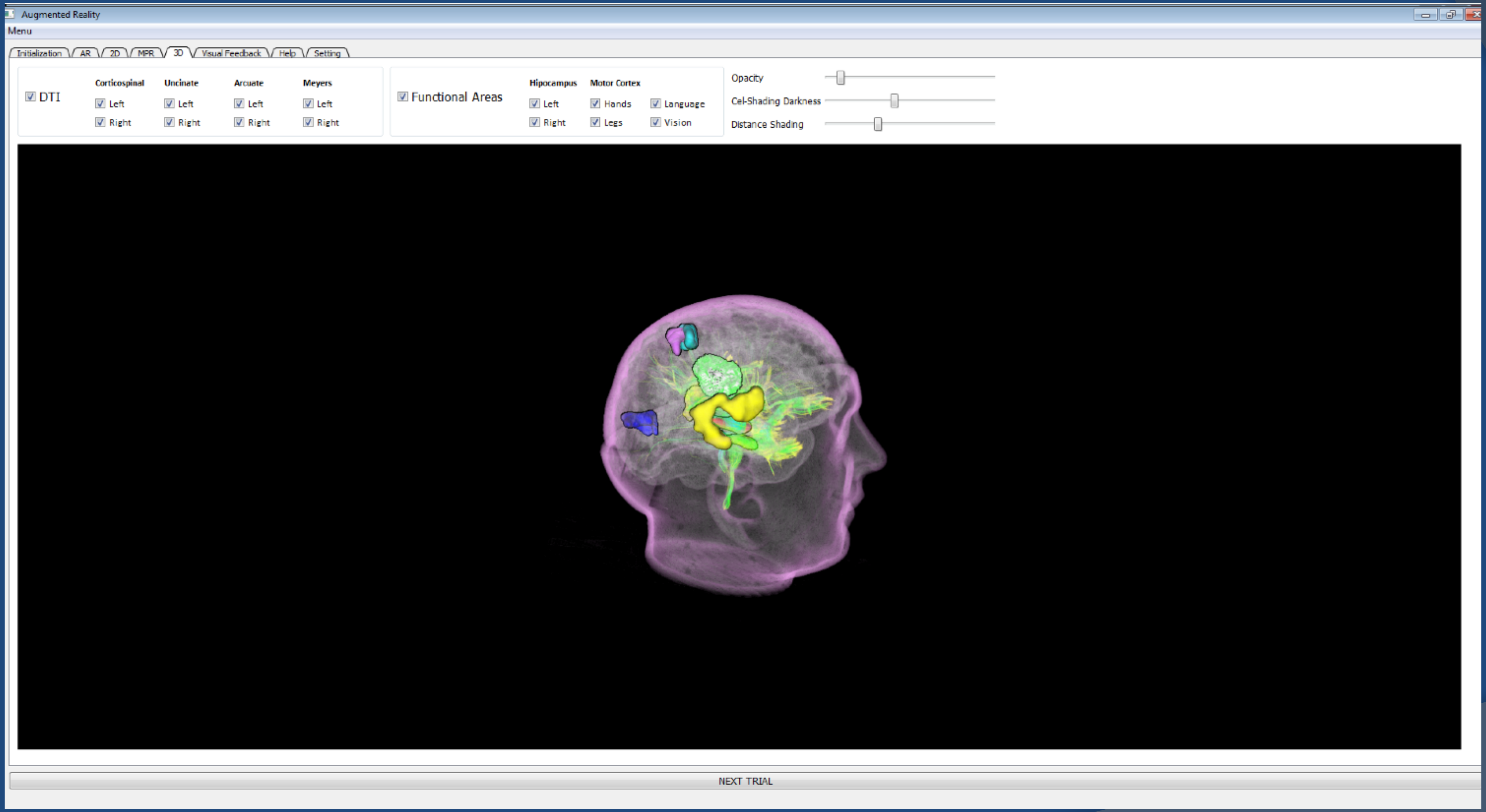
Tumour Biopsy (ortho views)



Tumour Biopsy (augmented VR cross planes)

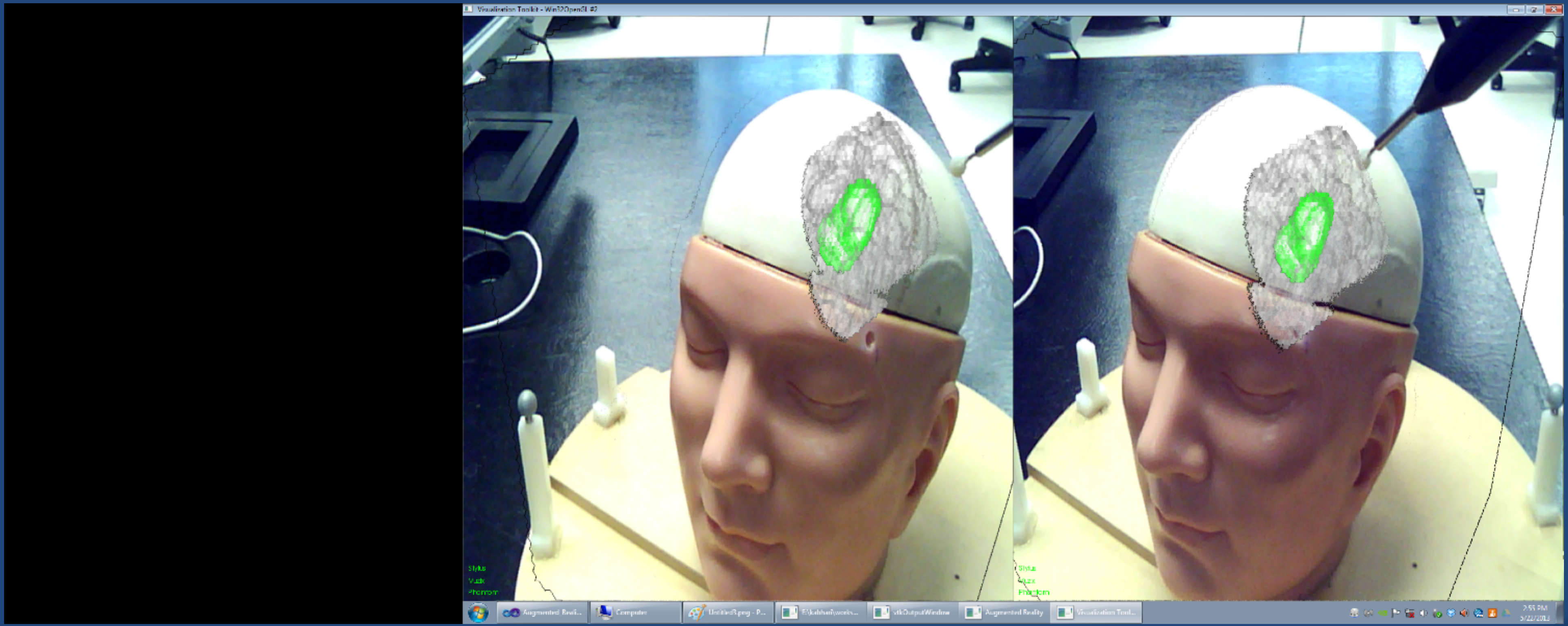


Tumour Biopsy (Augmented volumetric view)



Tumour Biopsy (Augmented Reality)

:



- Tumour Biopsy (Kamyar Abhari, TP, SdR, RE)

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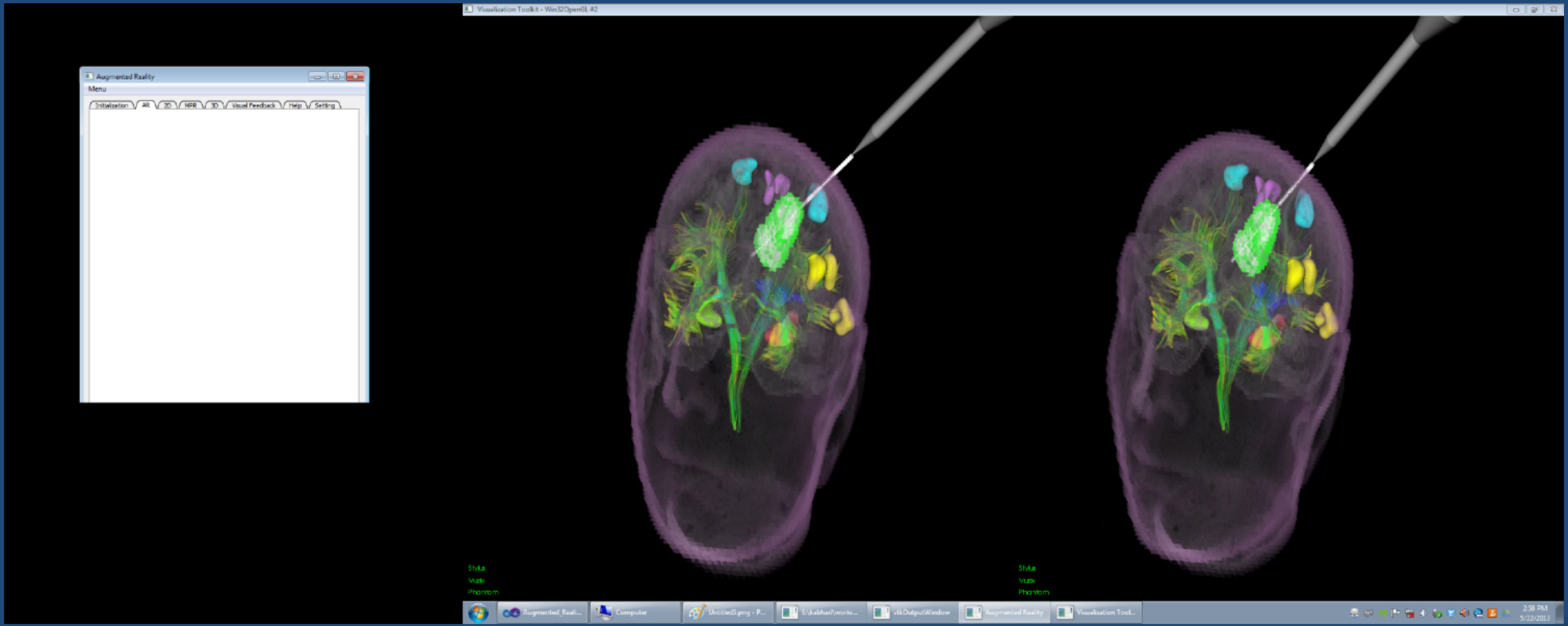
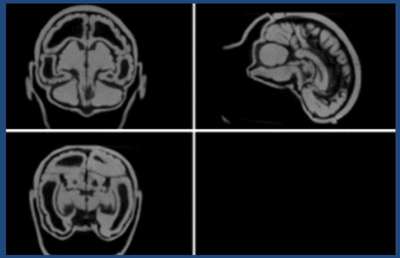


- Tumour Biopsy (Kamyar Abhari, TP, SdR, RE)

:

Evaluation Studies: Phase I



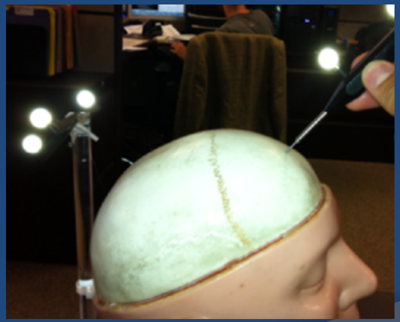
Visualize in given environment

e.g., 2D

Perform a task

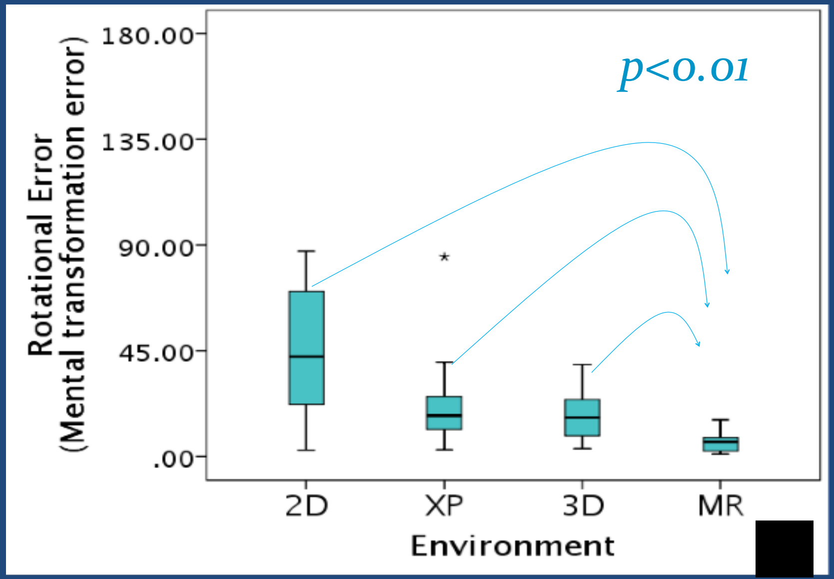
e.g., finding longest axis

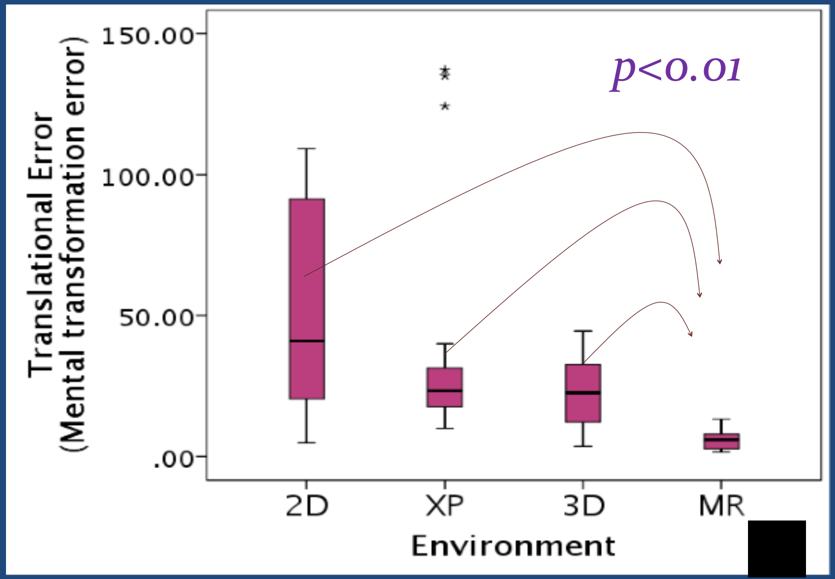
Specify optimal point of entry/ surgical path



Analyze (Accuracy/ Time)

Evaluation Studies



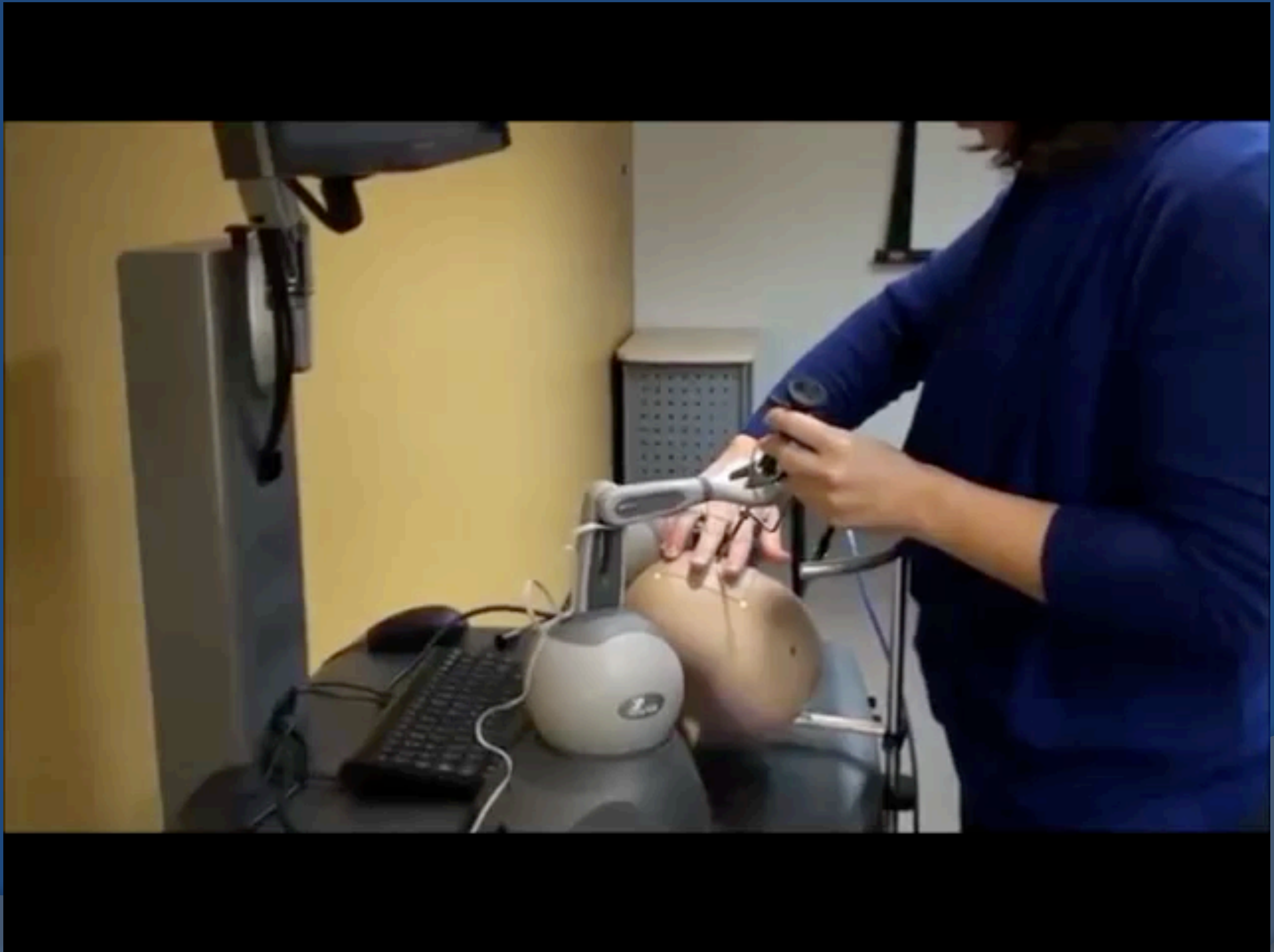


- Significant improvement of performance in AR while providing assistance
  - AR reduces the need for mental transformation required in the 2D/XP/3D viewing modes

- To cite the following material, please use:

- Eagleson,Roy (2016) "Hierarchical Task Representations of Surgical Interventions" Opening **Invited Keynote Lecture** at M2CAI workshop on Modeling and Monitoring of Computer Assisted Interventions, at 19th Int'l Conf on Medical Image Computing and Computer Assisted Intervention: MICCAI 2016, Athens, Greece. Oct 17-21, 2016.

NeuroTouch trainer for ETV:



Example Task Decomposition:

- Endoscopic Third Ventriculostomy

- Task Analysis: Burr Hole selection, Angle of approach, Insertion and Navigation within the Ventricle, Identification of Membrane, Site Selection, and Fenestration. (then verification.) Metrics: Speed/accuracy at each phase

HLTHSIM – Canadian NCE project: Graphics, Animation, and New Media for Healthcare Education (cf. Surgical Simulators projects)

Unifying Analytical Framework: Abstration Levels for Complex Tasks

Our analysis of a broad range of Surgical Skills training methodologies leads us to decompose these applications into levels of a VR-based abstraction hierarchy: (cf. Herb Simon & Allen Newell, 1972; Albus '81)

1. Cognitive or 'Knowledge Level' (assessment)
2. Decision-theoretic (reasoning, planning)
3. 'Action Scripts' or tasks (rehearsed responses to typical scenarios)
4. Kinematic Skill (positioning, grasping, moving)
5. Dynamical Skills (forces, balance, pressure)

Scenario Development at each level must include Evaluation of Training:
Objective Evaluation: Task Time, Error Rates + Subjective Evaluations

Newell and Simon: Cognitive Science and the span of Levels of Abstraction

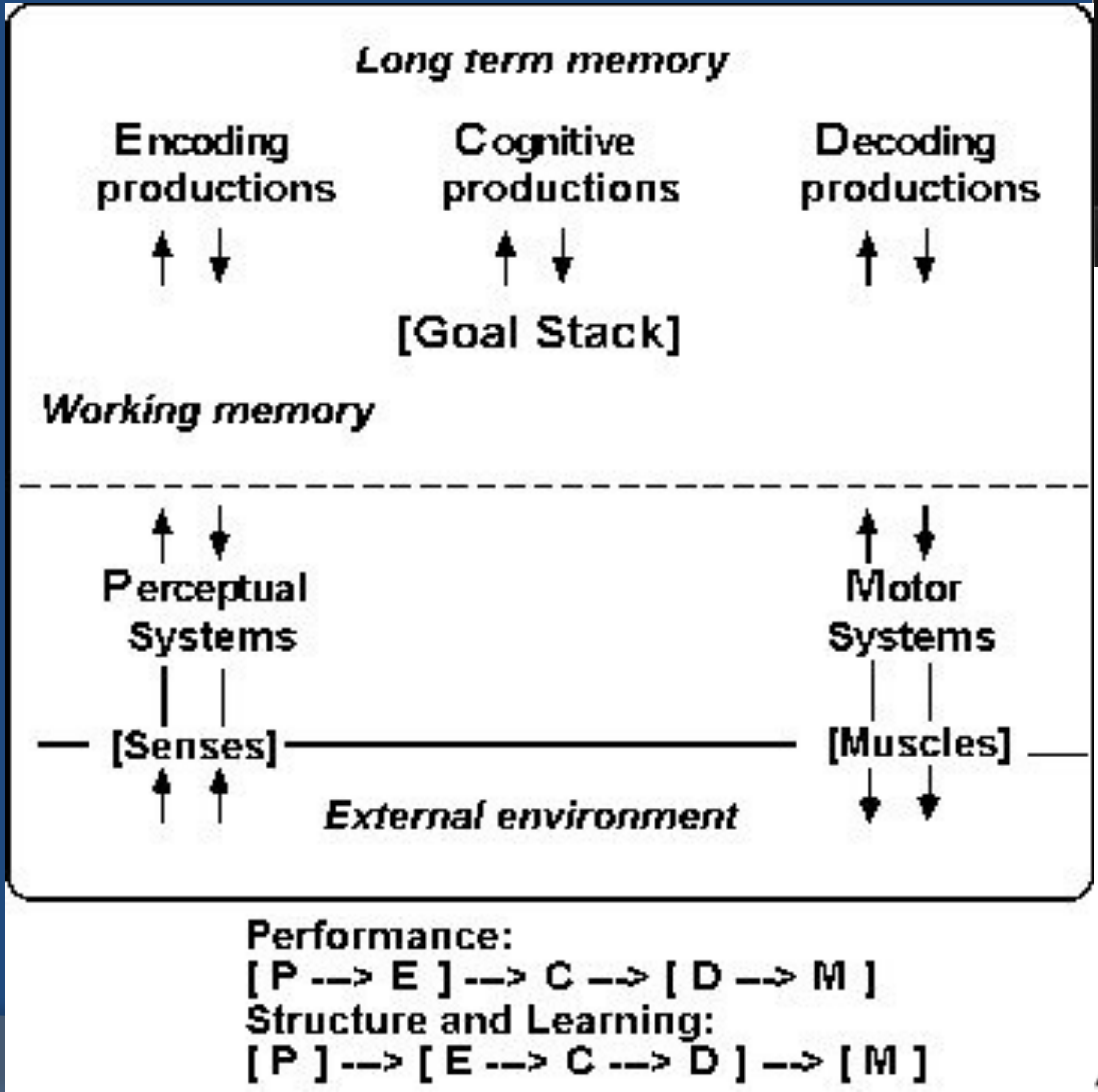
e.g. Perceptual Hierarchy: (read bottom-to-top!)

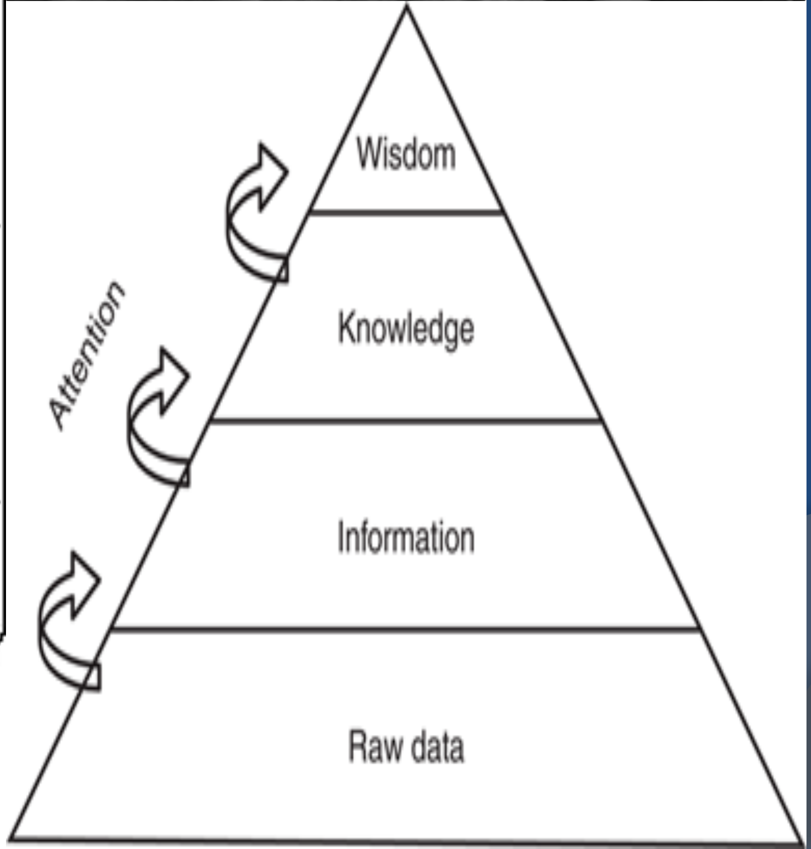
- Knowledge about Scene
- Spatial Reasoning (cognitively-guided perception, attention)
- Spatial Relations, indexing, identity
- Parsing Objects and parts
- Primitive Shape cues (Shape from: shading, stereo, motion, texture, etc)
- Detectors / Filters (Edges, gradients)
- Image (Retina / Transducers)

Allen Newell
(1927-1992)

Herbert Simon
(1916-2001)

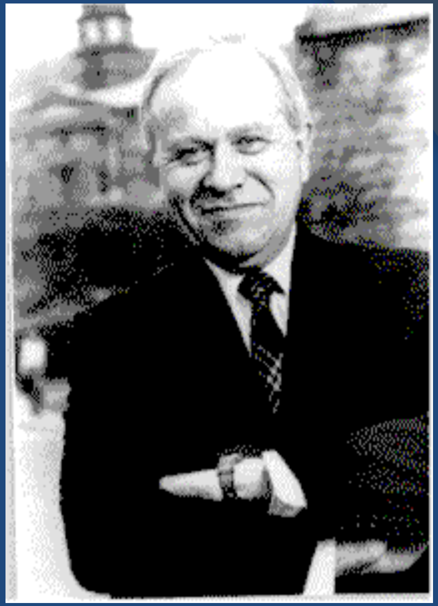
Task abstraction levels: Simon and Newell



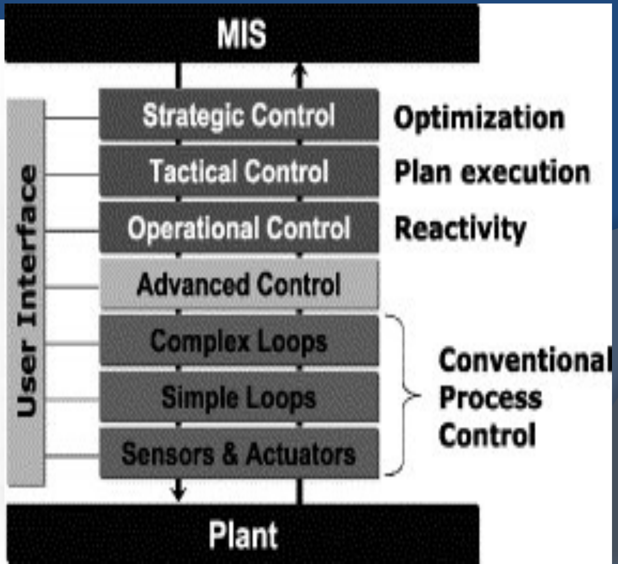


Hierarchical Control for Complex Tasks

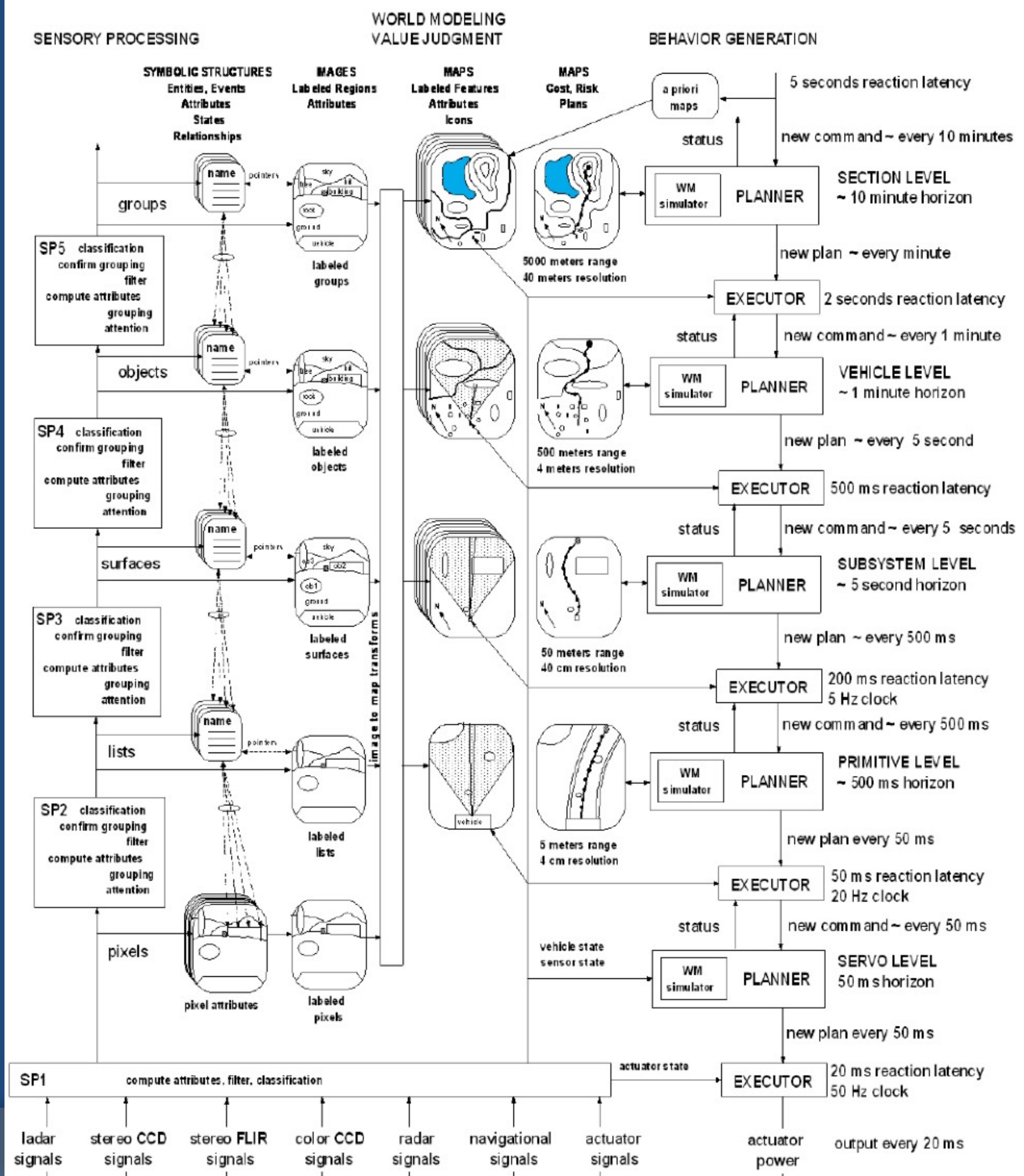
George Zames work included theories for how hierarchies were the solution to complexity in control problems.
E.g. G. Zames, “Feedback and Complexity,” in Proc. IEEE Decision and Control Conf., 1977.



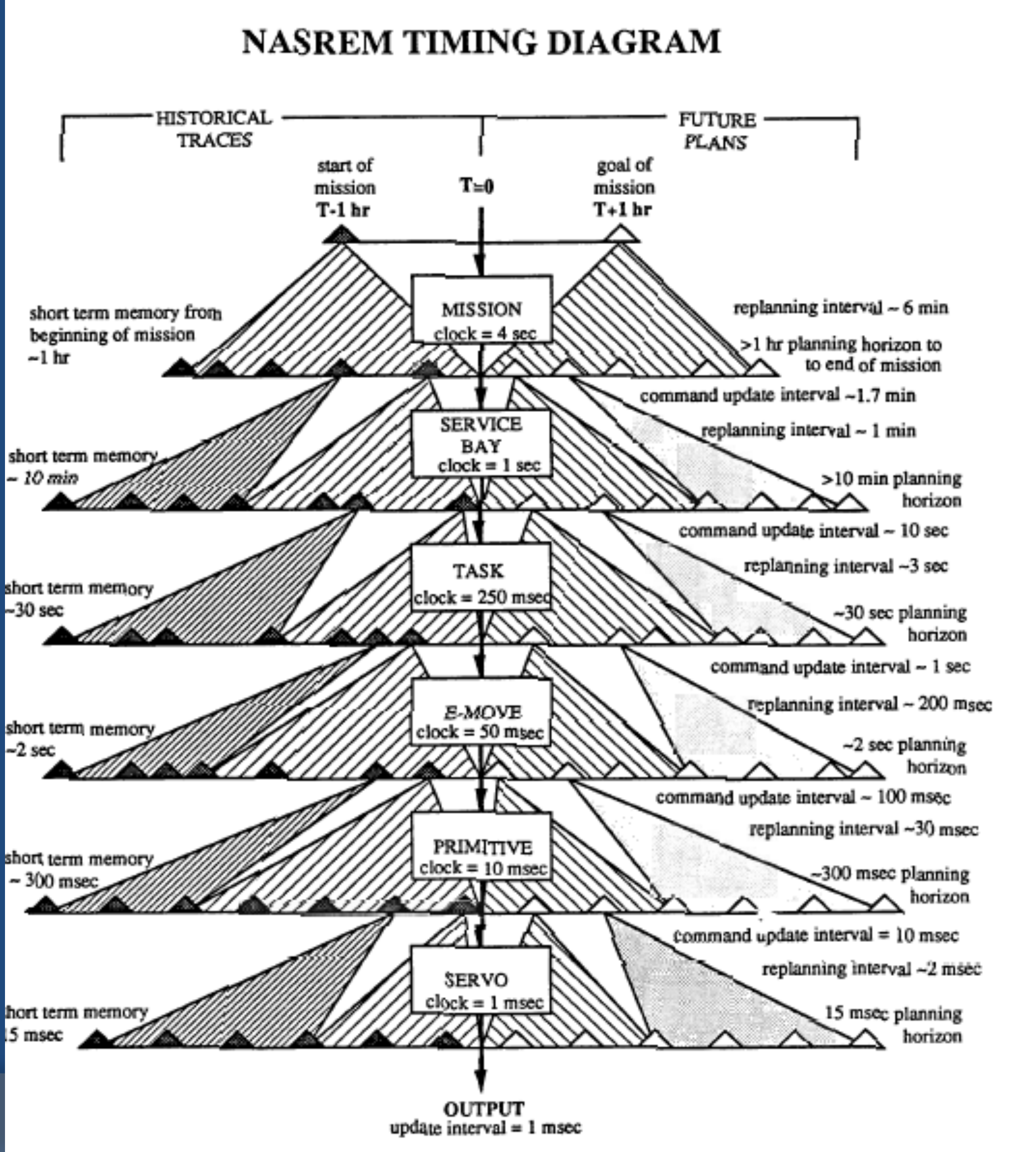
Sheridan, T. B. (Ed.) (1976). Monitoring behavior and supervisory control. Springer.
Sheridan, T. B. (1992). Telerobotics, automation, and human supervisory control. MIT Press.
Sheridan, T. B. (2002). Humans and automation: System design and research issues. Wiley.

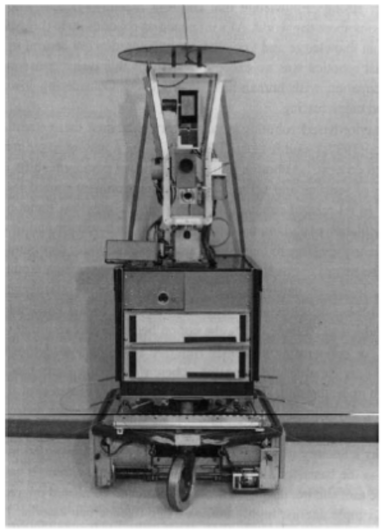


Decomposition into levels of skill for task completion

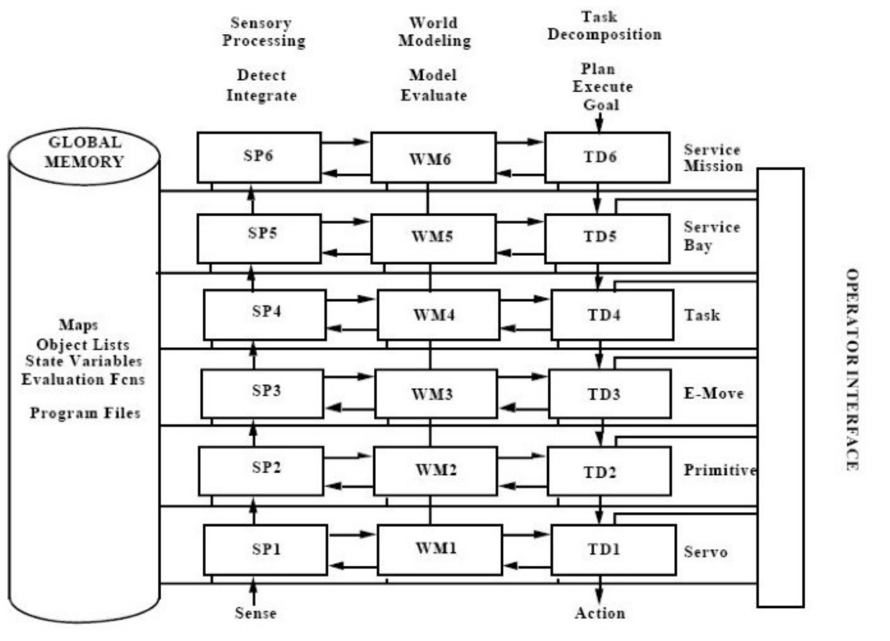


Task abstraction levels: James Albus





Shakey (SRI), 1960's



Task abstraction: Albus

Information Sciences 180 (2010) 1519–1554

Contents lists available at ScienceDirect

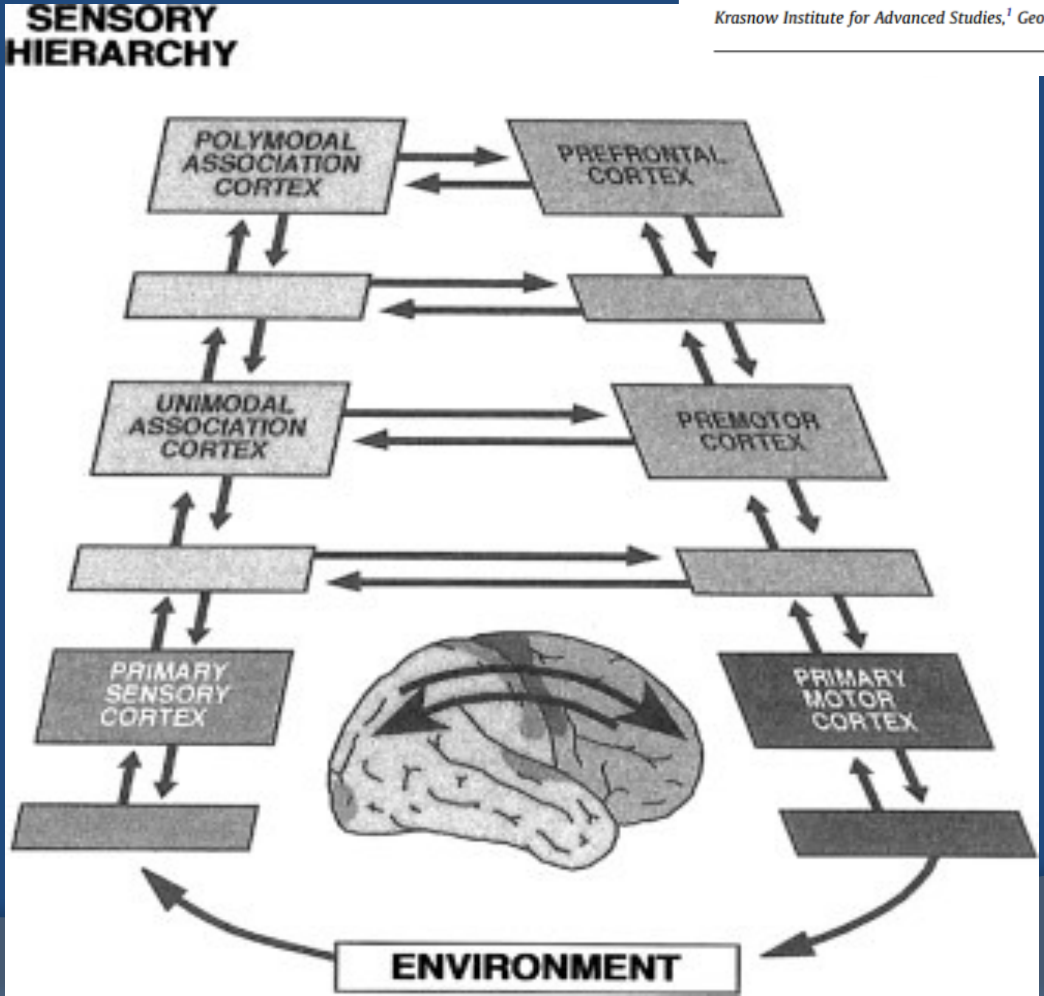
Information Sciences

journal homepage: www.elsevier.com/locate/ins

A model of computation and representation in the brain

James S. Albus *

Krasnow Institute for Advanced Studies,[1] George Mason University, Fairfax, VA, USA



In Memory of Dr. James Albus

(May 4, 1935 – April 17, 2011)

Dr. James S. Albus founded and led the Intelligent Systems Division at the National Institute of Standards and Technology where he was a Senior Fellow for the last 10 years. Dr. Albus has made many scientific contributions -- in the 1960's he designed electro-optical systems for more than 15 NASA spacecraft; the 1970's, he developed a theoretical model of the cerebellum, invented the CMAC neural net, and coinvented the Real-time Control System.

Abstraction Levels for Skills in Medical Education *[read from bottom-to-top!]*

Domain Knowledge: knowledge and skills relevant for diagnosis, namely the logical reasoning necessary for evaluation of the situation and the patient. Assessment of these skills is necessarily comprehensive and quite subjective.

Planning and Decision Making: For example, at the scene of an accident where emergency medicine technicians have to plan the on-site care. Decision making involves grouping, coordinating and communicating a number of tasks among several individuals and diverse disciplines to achieve a result. Evaluation at this level are task time and error rates, scored in accord with the enacted plan of experts.

subTask-level activities occur within a small time involving a motor action and may also require a basic decision. Tasks may be simple with no decisions involved (tying a knot) or composed of sub-tasks (wound closing). Task can be difficult to assess, since there may be no explicitly "true or wrong" task executions, so timing can still be looked at (especially in simple tasks), but accuracy is more important than error rate (not binary but scaled).

Movement level (kinematics): For example in endoscopic surgery, the surgeon has to reach the target with the forceps while looking at the screen. At this level, assessment involves considering both speed and accuracy.

Dynamics and Forces/Haptics: The physics-based level involves training and evaluation of motions at the dynamic level; evaluated on the basis of appropriate forces.

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Movement level (kinematics): For example in endoscopic surgery, the surgeon has to reach the target with the forceps while looking at the screen. At this level, assessment involves considering both speed and accuracy.

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Index of Performance for any Task

Ip = (Index of Difficulty) / (Task time)

"Performance = Speed x Accuracy"

The Index of Difficulty is related to the inverse of the probability of the task being accomplished by luck (chance)
(Lower tolerance for error = "Accuracy" = "Difficulty")

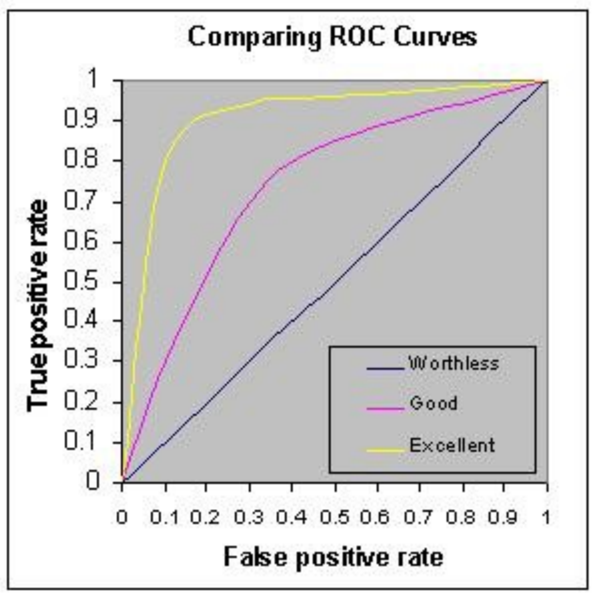
Abstract Entropy terms: - log (p(chance))

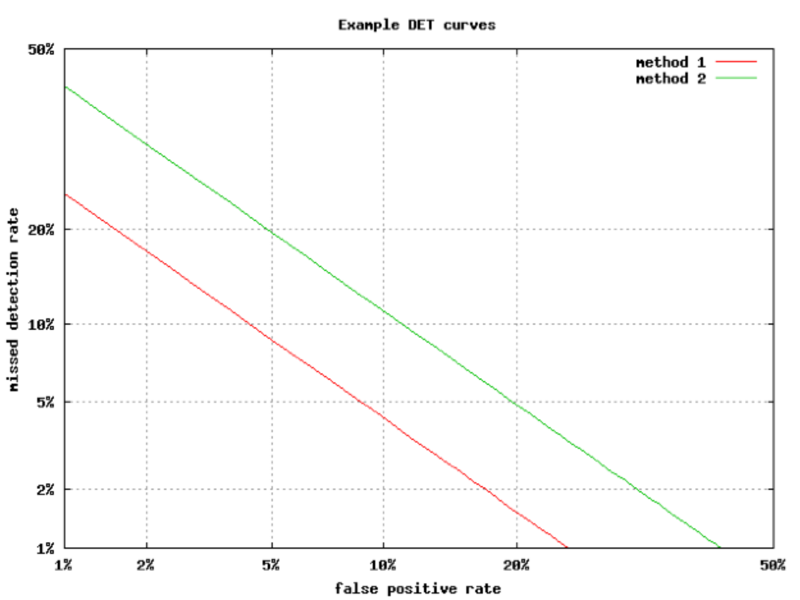
For any level of a task hierarchy, your 'skill' is 'surprise' -- it accounts for the fact that you have accomplished a task (compared to doing it by luck)

Index of Performance for a perceptual detection task?

Ip = (Index of Difficulty) / (Task time)

Performance according to signal detection theory:
(area under ROC curve per task time)
Alternately: Use DET curve C_{llr} (log-likelihood ratio)
Entropy = - log (f(AUC))

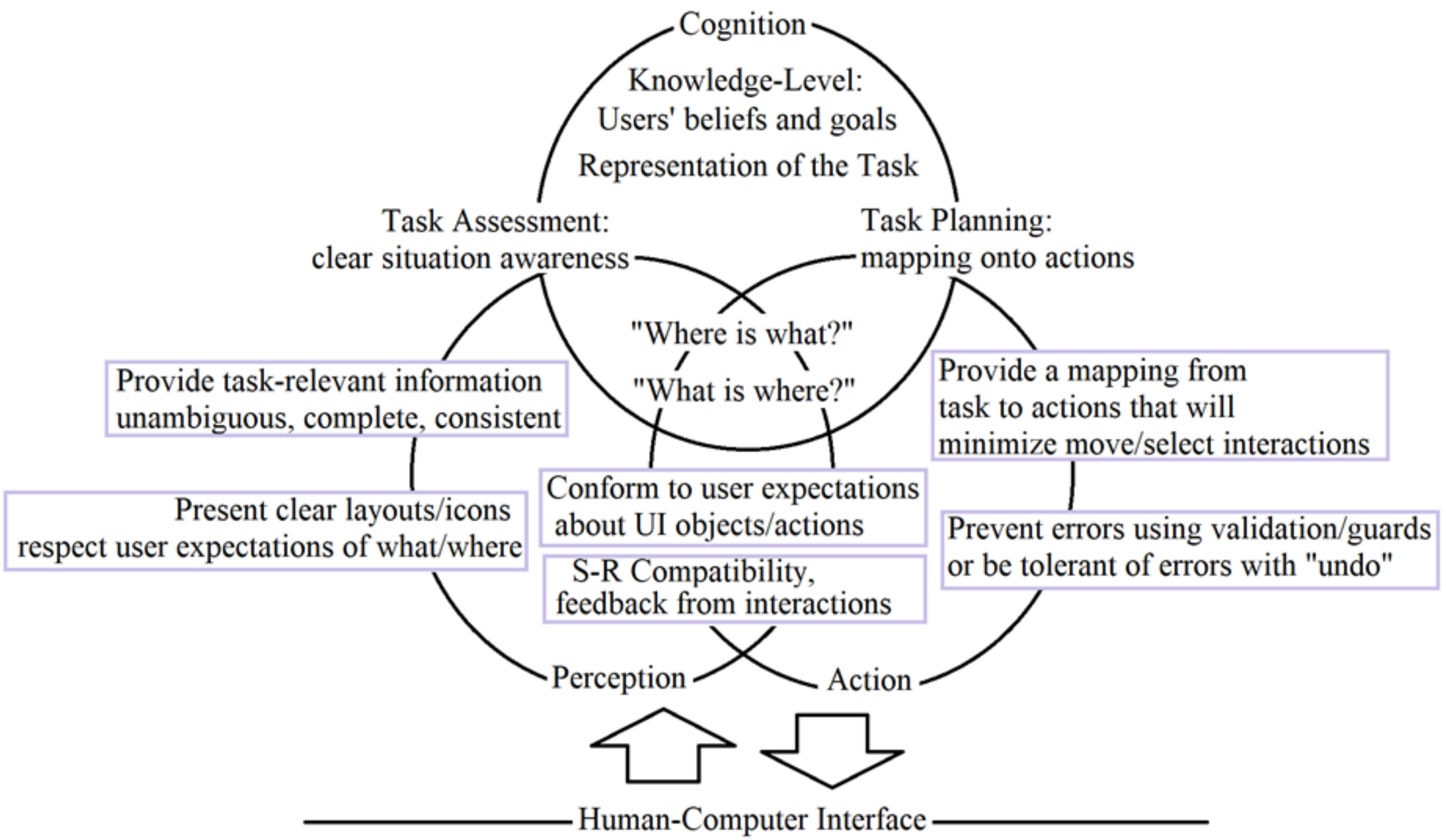




Validity: Internal vs External

- Trade-off Exists:
- A test's internal validity is the degree to which its methodology has operationalized factors, isolated into measures for recording as data for analysis.
- A test's external validity is the degree to which the sampled data and behaviours reflect the bigger picture of the domain

Design Guidelines– provide a concise summary of ‘classical’ guidelines from literature



10 Basic Principles

From Nielsen's web page: http://www.useit.com/papers/heuristic/heuristic_list.html

1. Visibility of system status
2. Match between system and the real world
3. User control and freedom
4. Consistency and standards
5. Error prevention
6. Recognition rather than recall
7. Flexibility and efficiency of use
8. Aesthetic and minimalist design
9. Help users recognize, diagnose, and recover from errors
10. Help and Documentation

- Slightly different from text book list

70 More Guidelines

1) Things that look different should act different.
2) If it is not needed, it's not needed.
3) The information for the decision needs to be there when the decision is needed.
4) The user should control the system. The system shouldn't control the user. The user is the boss, and the system should show it.
5) The idea is to empower the user, not speed up the system.
6) Don't overload the user's buffers.
7) Keep it simple.
8) Things that look the same should act the same.
9) The user should be able to do what the user wants to do.
10) Every action should have a reaction.
11) Everything in its place, and a place for everything.
12) Let people shape the system to themselves, and paint it with their own personality
13) Error messages should actually mean something to the user, and tell the user how to fix the problem.
14) The best journey is the one with the fewest steps. Shorten the distance between the user and their goal.
15) Everyone makes mistakes, so every mistake should be fixable.
16) The more you do something, the easier it should be to do.

70 More Guidelines, cont.

17) Cute is not a good adjective for systems.
18) Keep it neat. Keep it organized.
19) Consistency, consistency, consistency.
20) The user should always know what is happening.
21) Minimize the need for a mighty memory.
22) Know they user, and YOU are not thy user.
23) If I made an error, at least let me finish my thought before I have to fix it.
24) Design for regular people and the real world.
25) Eliminate unnecessary decisions, and illuminate the rest.
26) You should always know how to find out what to do next.
27) If I made an error, let me know about it before I get into REAL trouble.
28) Even experts are novices at some point. Provide help.
29) Provide a way to bail out and start over.
30) Don't let people accidentally shoot themselves.
31) Color is information.
32) The user should be in a good mood when done.
33) The fault is not in thyself, but in thy system.
34) To know the system is to love it.
35) Deliver a model and stick to it.

70 More Guidelines, cont.

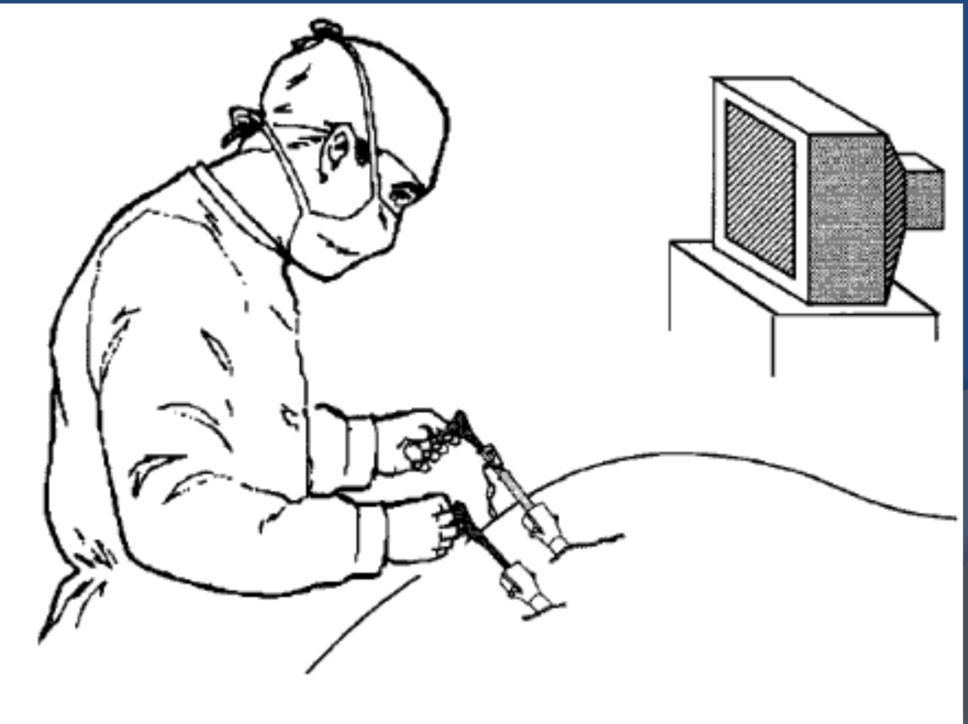
36) Follow platform conventions.
37) Make it hard for people to make errors.
38) The system status (i.e., what's going on should always be visible.
39) Accommodate individual differences among users through automatic adaptation or user tailoring of the interface.
40) Make it easy for a beginner to become an expert.
41) No you can't just explain it in the manual.
42) Provide user documentation that is easy to search, focused on the user's task, lists concrete steps to be carried out, and is not too large.
43) The system should speak the users' language, following real-world conventions.
44) Instructions for use of a system should be visible or easily retrievable.
45) What does marketing want? Ok, now how do we show them they're wrong?
46) What does management think it wants? Ok, now how do we show them they're wrong?
47) Allow users to tailor frequent actions.
48) Users don't know what they want, and users can't always say what they know.
49) Roll the videotape.
50) Common sense is an uncommon commodity
51) Make objects, actions, and options visible.

70 More Guidelines, cont.

52) Data drives good design.
53) Help users develop a conceptual representation of the structure of the system.
54) Minimize the amount of information a user must maintain in short-term memory.
55) It's a jungle. Be careful out there.
56) People should not have to remember information across a dialogue.
57) Make it impossible to make errors that will get the user into REAL trouble.
58) Dialogues should not contain information that is irrelevant or rarely needed.
59) Testing, testing, testing.
60) Keep the user mental workload within acceptable limits.
61) Minimize the amount of information recoding that is necessary.
62) Minimize the difference in dialogue both within and across interfaces.
63) An ounce of good design is worth a pound of technical support.
64) Provide the user with feedback and error-correction capabilities.
65) So how is this better than what the competition is doing?
66) Provide good error messages that are expressed in plain language, precisely indicate the problem, and constructively suggest a solution.
67) Whadya mean, they're not all computer scientists?
68) Support undo and redo.
69) Different words, situations, or actions should result in different things happening.
70) The best user interface is one the user doesn't notice.

Capacities of the Human in the System
(+) Perception
(+) Action
(+) Cognition

Constraints and Limitations:
(-) Perception is effortless; but not cognitively penetrable
[training and expertise cannot overcome perceptual/motor illusions]



eagleson @ uwo.ca