



Center for
**LifeLong
Learning
& Design**

University of Colorado at Boulder

Wisdom is not the product of schooling
but the lifelong attempt to acquire it.
- Albert Einstein

Distributed Intelligence: Extending the Power of the Unaided, Individual Human Mind

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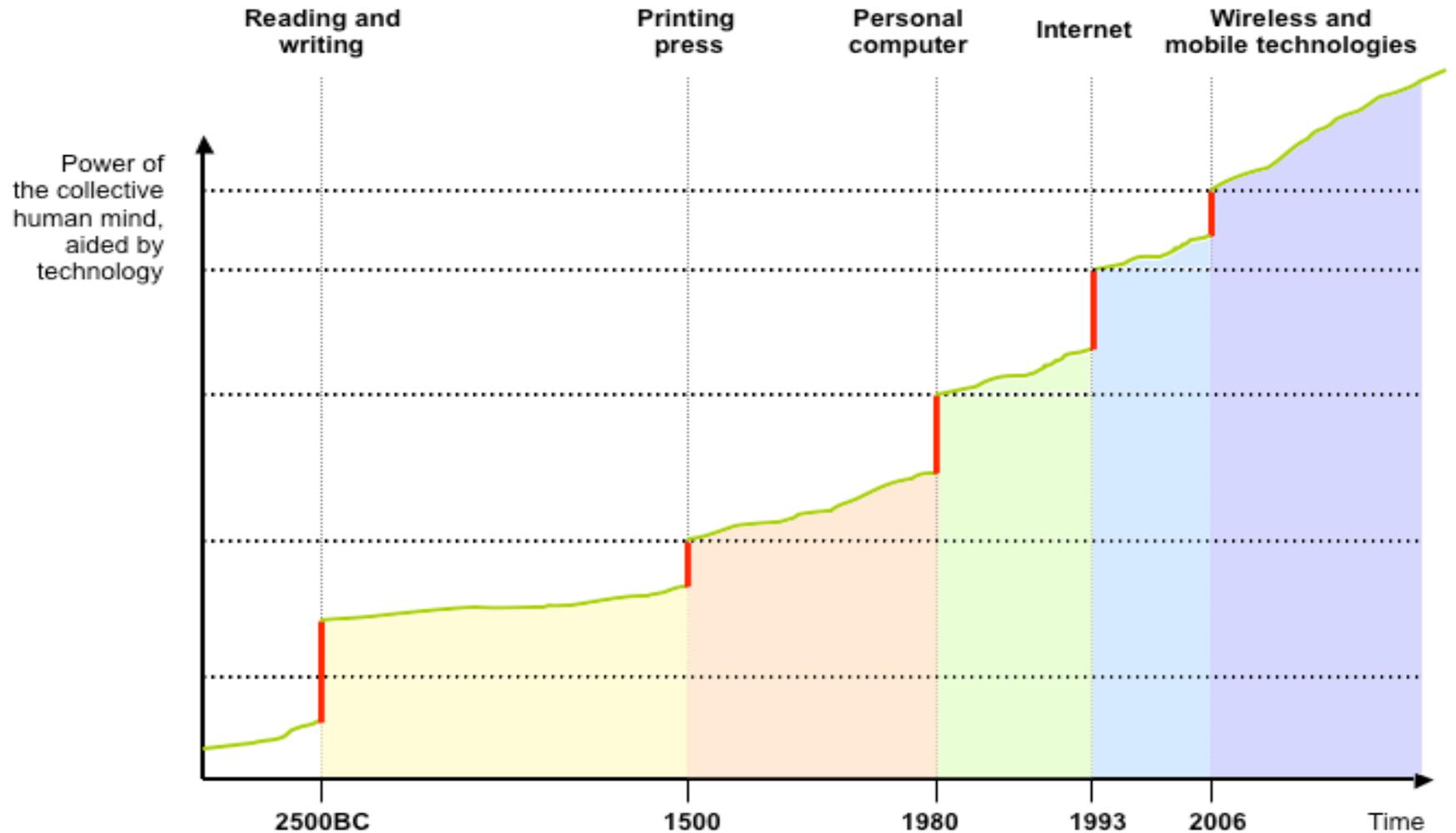
Overview

- ♣ Basic Message
- ♣ Beyond the Unaided, Individual Human Mind: New Media and Technologies
- ♣ Distributed Intelligence
- ♣ Conceptual Frameworks
- ♣ Socio-Technical Environments
 - CLever: Cognitive Levers
 - EDC: Envisionment and Discovery Collaboratory
- ♣ Challenges and Questions for the Future
- ♣ Conclusions

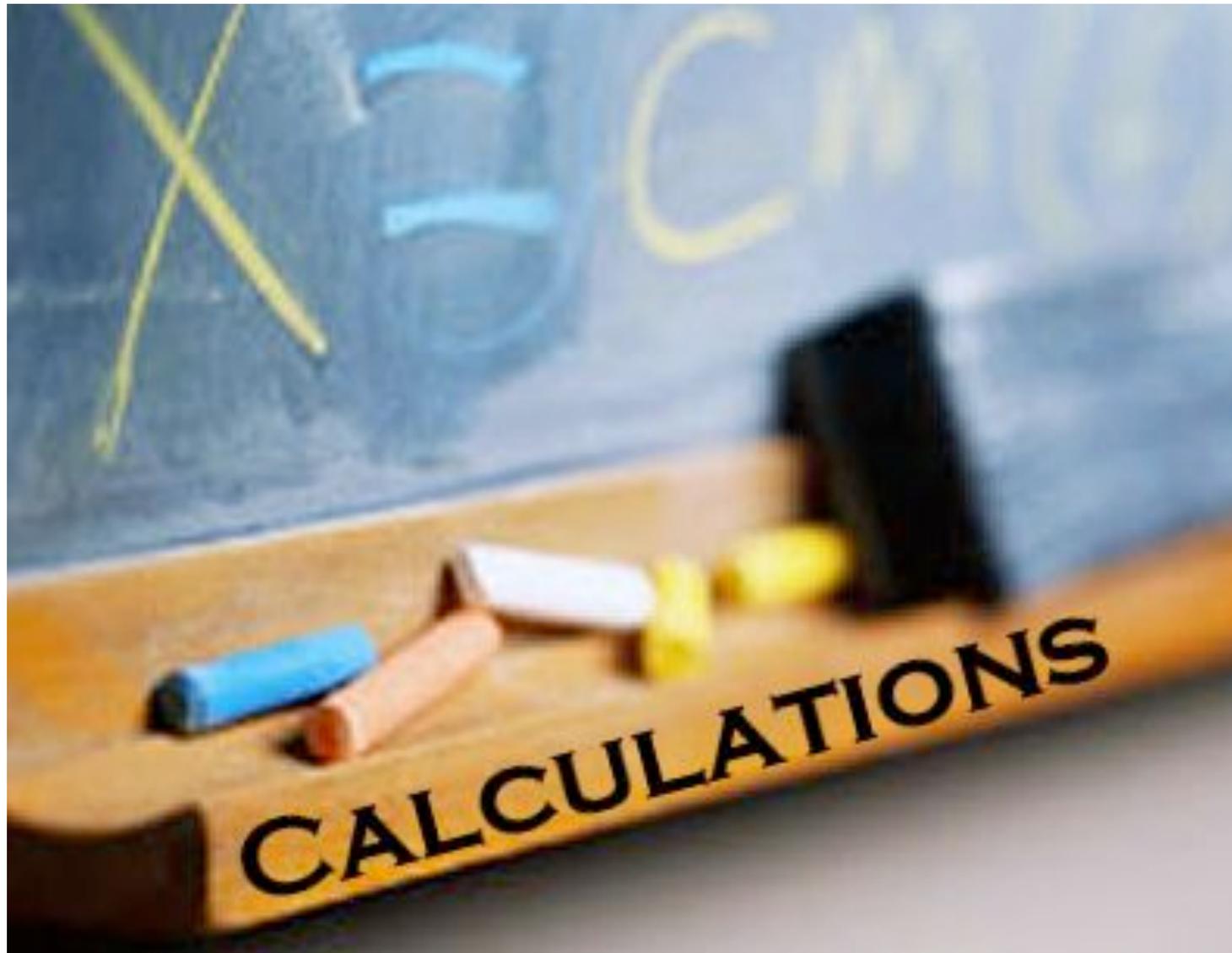
Basic Message

- ♣ thinking, knowing, working, and learning will further **transcend the unaided individual human** mind in the 21st century ◇ this is not a luxury, but a necessity
- ♣ innovative media and technologies (“**socio-technical environments**”) are of critical importance supporting new levels of **distributed intelligence**

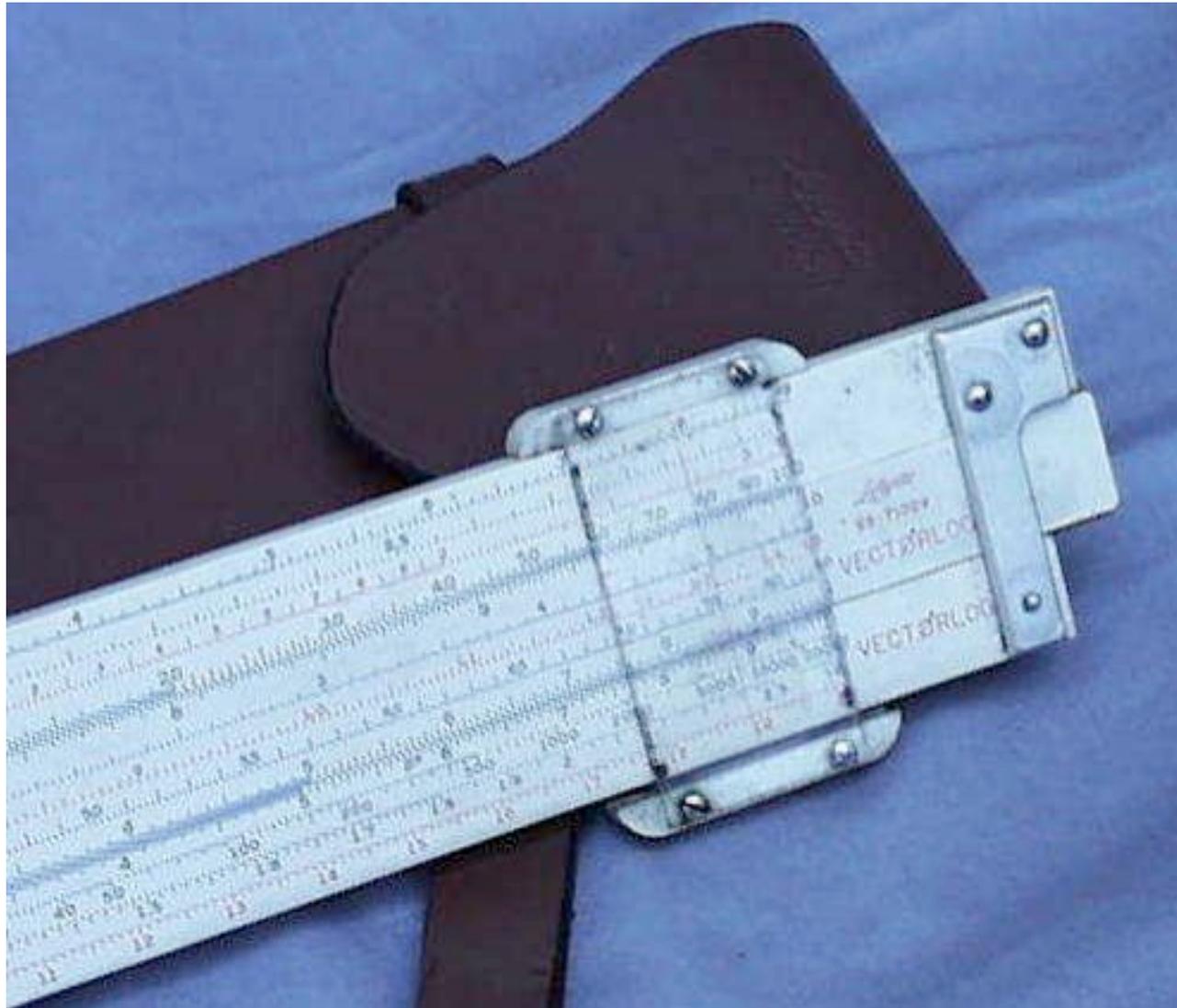
Beyond the Unaided, Individual Human Mind



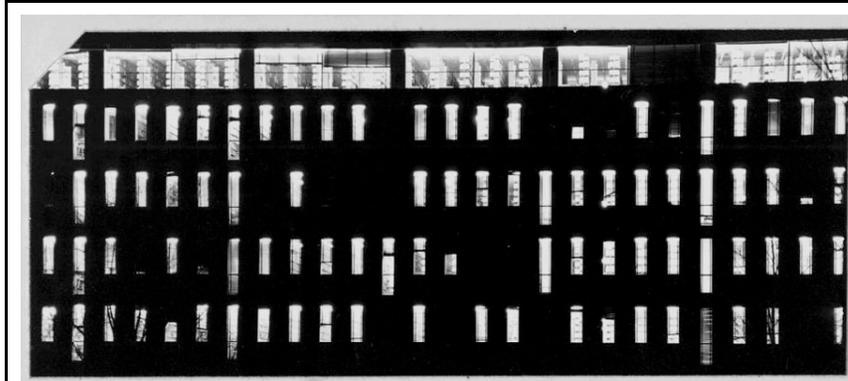
Thinking and Learning = f{Media} — In “Ancient” Times: Blackboards



Thinking and Learning = f{Media} — In the “Very Old” Days: Slide-Rules



Thinking and Learning = f{Media} — In the “Old” Days: Computing with Punch Cards



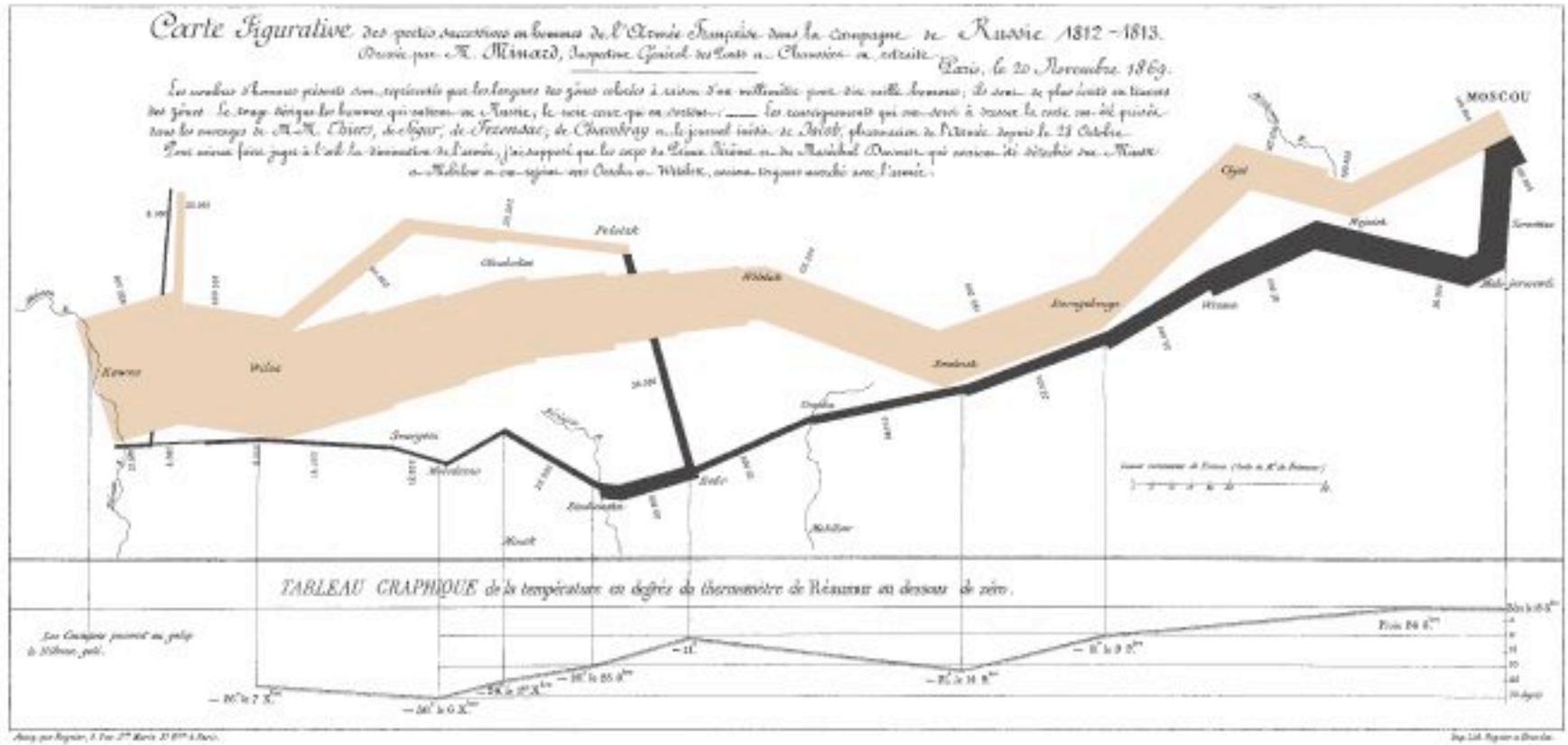
Thinking and Learning = f{Media} — Yesterday: The Personal Computer



Thinking and Learning = f{Media} — Today: Wireless and Mobile Technologies (WMT)



Thinking and Learning = f{Media}: Examples of Visualizations: Minard's Napoleon's March to Moscow



Visible Human Project

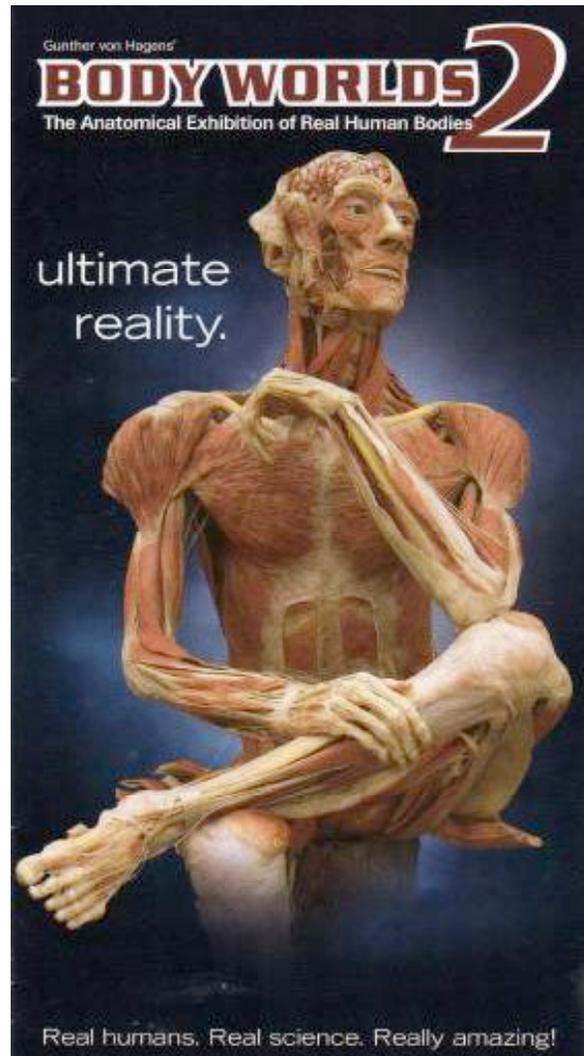
Center for Human Simulation, CU HSC

http://www.uchsc.edu/sm/chs/browse/browse_m.html



Body Worlds

the anatomical exhibitions of real human bodies



Body Worlds

the anatomical exhibitions of real human bodies



Distributed Intelligence

♣ **claim:** *human cognition* has been seen as existing **solely** “inside” a person’s head, and studies on cognition have often disregarded the physical and social surroundings in which cognition takes place

♣ **distribution among people:**

- all of us are knowledgeable in some domains and not in others (“symmetry of ignorance”)
- division of labor + specialization
- collaborative learning and working (CSCL and CSCW)

♣ **distribution between humans minds and artifacts**

- changing tasks and intelligence augmentation
- external representations (**visualizations**)

♣ the two distributions can and should be **integrated** ◇ socio-technical environments

Two Perspectives on Distributed Intelligence

- ♣ **personal point of view:** distributed intelligence **changes the nature of the tasks** which human beings have to do creating new divisions of labor
 - source: Norman, D. A. (1993) Things That Make Us Smart, Addison-Wesley Publishing Company, Reading, MA.
 - **examples:**
 - check-out clerk in a supermarket
 - pilot flying a modern airplane

- ♣ **system point of view:** the “person + artifact” is smarter than either alone
 - source: Engelbart, D. C. (1995) "Toward Augmenting the Human Intellect and Boosting Our Collective IQ," Communications of the ACM, 38(8), pp. 30-33.
 - Einstein: “My pencil is cleverer than I”
 - **examples:** socio-technical environments for
 - people with cognitive disabilities
 - cockpit (pilot + computers) of an airplane

Technologies Changing Tasks

From the Neighborhood Store to the Smart Store of the Future

- ♣ **media:** head \diamond pencil and paper \diamond adding machines \diamond UPC, scanners and databases, RFID tags
- ♣ **sales clerks:** adding prices
 - in their heads
 - using pencil and paper
 - using adding machines
 - using scanners
 - no need for their services anymore
- ♣ **money:** computing the change in the head \diamond by the machine \diamond processing credit cards
- ♣ **customer:**
 - checking out their own groceries (“do I want to do this?”)
 - walking by a RFID reader
- ♣ **overall performance of the system:** speed, reliability, visibility, cost

Why Distributed Intelligence?

A few Claims based on the work of Jerome Bruner

- ♣ human mental activity is **neither solo nor conducted unassisted**, even when it goes “inside the head”

- ♣ **“how the mind works”** is dependent on the tools at its disposal
(◇ “how the hand works” cannot be fully appreciated unless one takes into account whether it is equipped with a screwdriver, a pair of scissors)

- ♣ **externalizations, oeuvres, works, works-in-progress**
 - produce a record of our efforts, one that is “outside us” rather than simply in memory
 - produce situations talking back to us ◇ visualizations, critiquing
 - make our thoughts and intentions more accessible to reflective efforts
 - works-in-progress produce and sustain creativity with shared and negotiable ways of thinking in a group

Why Distributed Intelligence?

A few Claims based on the work of Merlin Donald

♣ **brain-culture symbiosis:** the human brain cannot realize its potential unless it is immersed in a distribution network

♣ **material culture:**

- externalizes memory and greatly amplifies the permanence and power of distributed cognition
- new media gradually freed the symbolization process from the limitations of biological memory
- the material culture sometimes overwhelms us with its richness

♣ **higher intelligence:**

- a product of marrying the raw intellectual power of the human brain to an appropriate technology
- think previously unthinkable thoughts
- “mind tools”: perform cognitive work, contribute symbolic technologies (musical notation, Arabic numerals)

Possible Roles for Humans and Computers in Distributed Intelligence

source: Norman, D. A. (1993) *Things That Make Us Smart*
black: human-centered view
blue: computer-centered view

Humans	Computers
creative, vague	dumb, precise
compliant, disorganized	rigid, orderly
attentive to change, distractible	insensitive to change, undistractable
resourceful, emotional	unimaginative, unemotional
flexible, inconsistent	consistent, inflexible

Conceptual Frameworks Grounded in a Distributed Intelligence Framework

♣ Beyond Advanced Visual Interfaces

- Human Computer Interaction: Explicit and Implicit Interaction Channels
- Human Problem-Domain Interaction

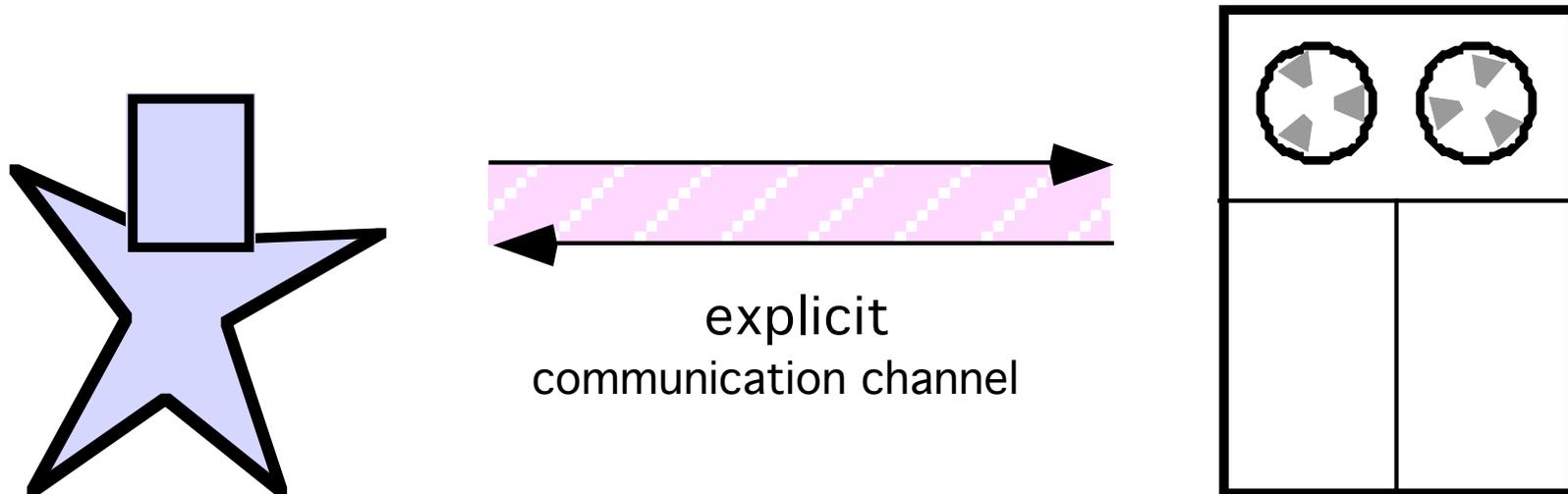
♣ Visualizations

♣ Information Overload

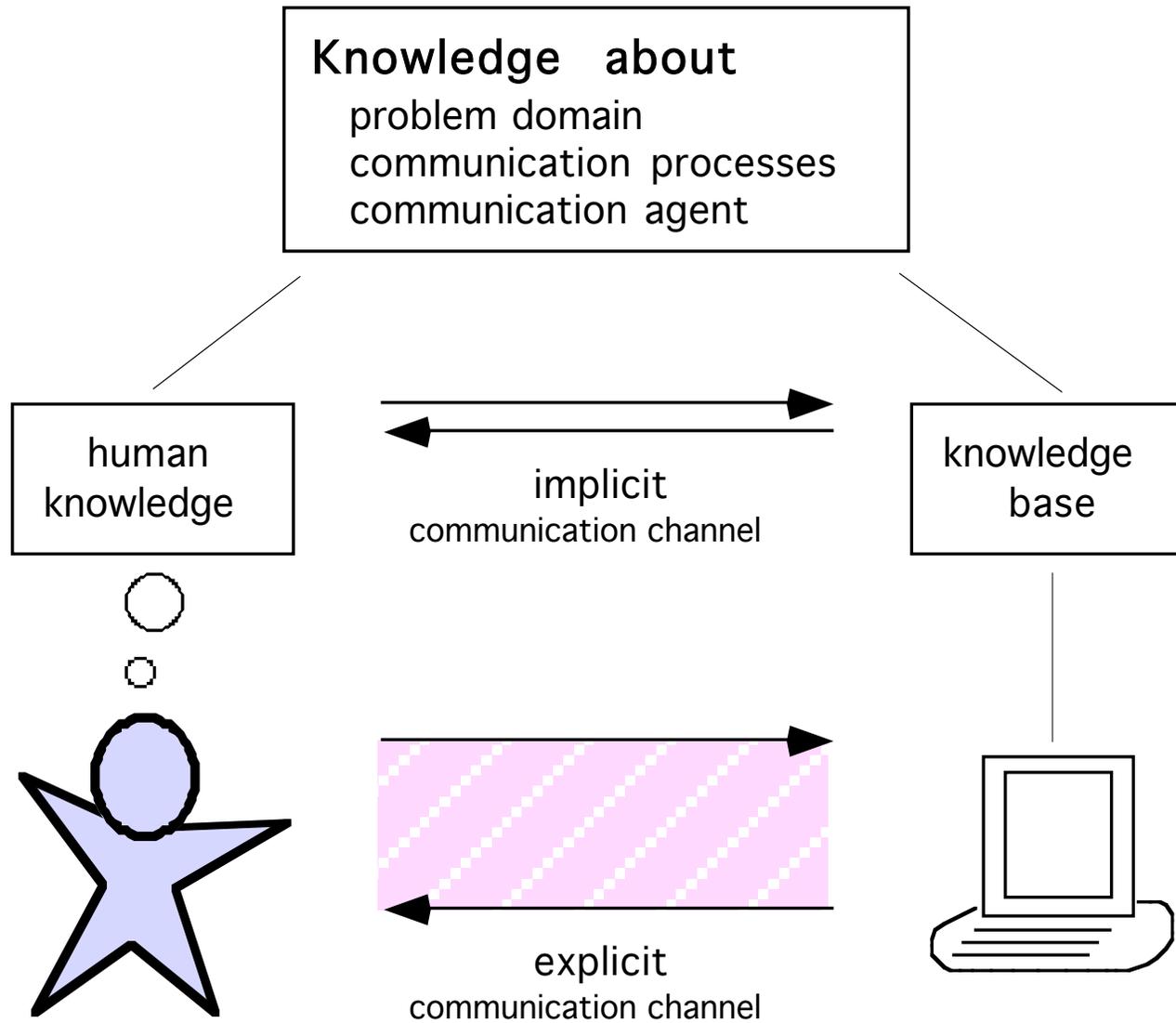
♣ Tools for Living ⇓⇓ Tools for Learning

The Beginning of Human-Computer Interaction (HCI)

Human and Computer connected by a narrow explicit communication channel

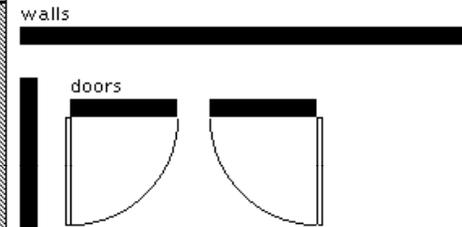
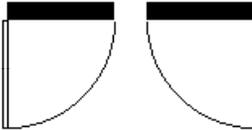
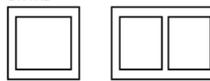
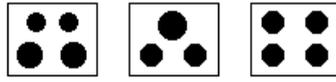
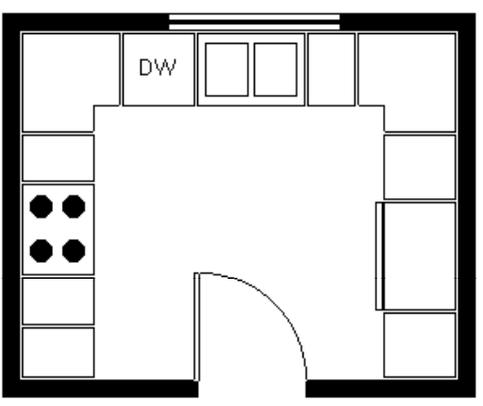
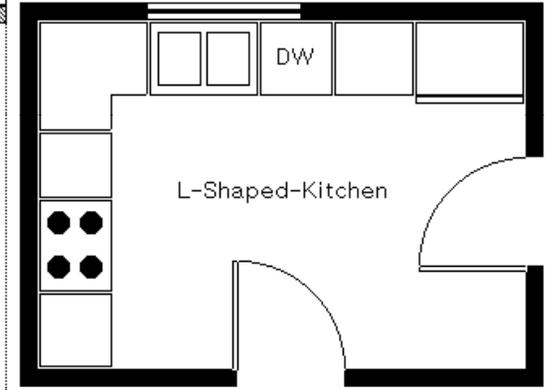


Knowledge-Based Human Computer Collaboration



Human Problem-Domain Interaction

Domain-Oriented Design Environments for Kitchen Design

<i>Janus-Construction</i>		Clear Work Area Load Catalog	Critique All Save In Catalog	Edit Global Descriptions Select Context
<p>Appliance Palette</p> <p>walls</p>  <p>doors</p>  <p>windows</p>  <p>sinks</p>  <p>stoves</p> 		<p>Work Area</p> 		
<p>Catalog</p>  <p>L-Shaped-Kitchen</p>		<p>Messages</p> <ul style="list-style-type: none"> • The length of the work triangle (Double-Bowl-Sink-1, Four-Element-Stove-1, Single-Door-Refrigerator-1) is greater than 23 feet. • Single-Door-Refrigerator-1 is not near Four-Element-Stove-1. 		
		<p>Commands</p> <ul style="list-style-type: none"> ▶ Critique All ▶ ■ 		

Visualization = In Search for Powerful External Representation

source: Simon, H. A. (1996) *The Sciences of the Artificial*, third ed., The MIT Press, Cambridge, MA.

- ♣ **informational efficiency:** two representations are *informationally equivalent* if all of the information in the one is also inferable from the other, and vice versa. Each could be constructed from the information in the other.
- ♣ **computational efficiency:** two representations are *computationally equivalent* if they are informationally equivalent and, in addition, any inference that can be drawn easily and quickly from the information given explicitly in the one can also be drawn easily and quickly from the information given explicitly in the other, and vice versa
- ♣ **informational equivalence versus computational equivalence of representations** ◇ “even if two representations contain exactly the same information, it may be far cheaper, computationally, to make some of this information explicit using one representation than using the other”

The Importance of Representations

♣ critical importance of representations:

“Solving a problem simply means representing it so as to make the solution transparent”

♣ number scrabble (“The Game of 15”)

- two person game
- numbers from 1 to 9
- players alternate and take one of the numbers
- the player who can add **exactly** three numbers in her/his possession to equal 15 will win

1, 2, 3, 4, 5, 6, 7, 8, 9

Tic-Tac-Toe

		X
	O	X
O		

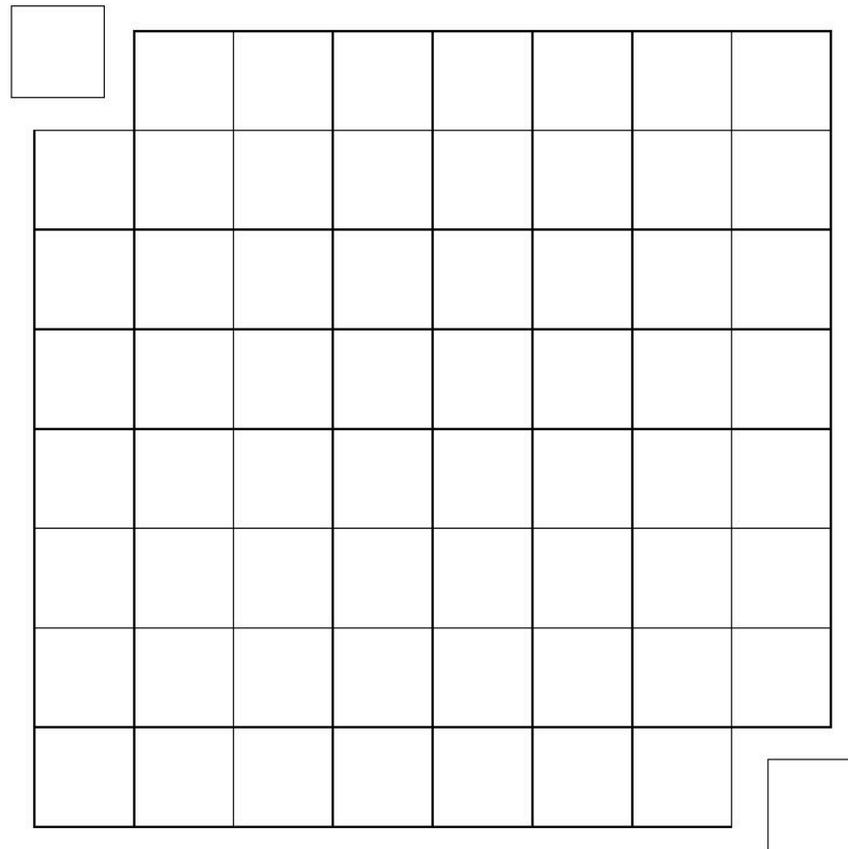
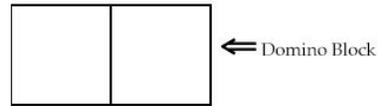
Number Scrabble and Tic-Tac-Toe: The “Same Game”

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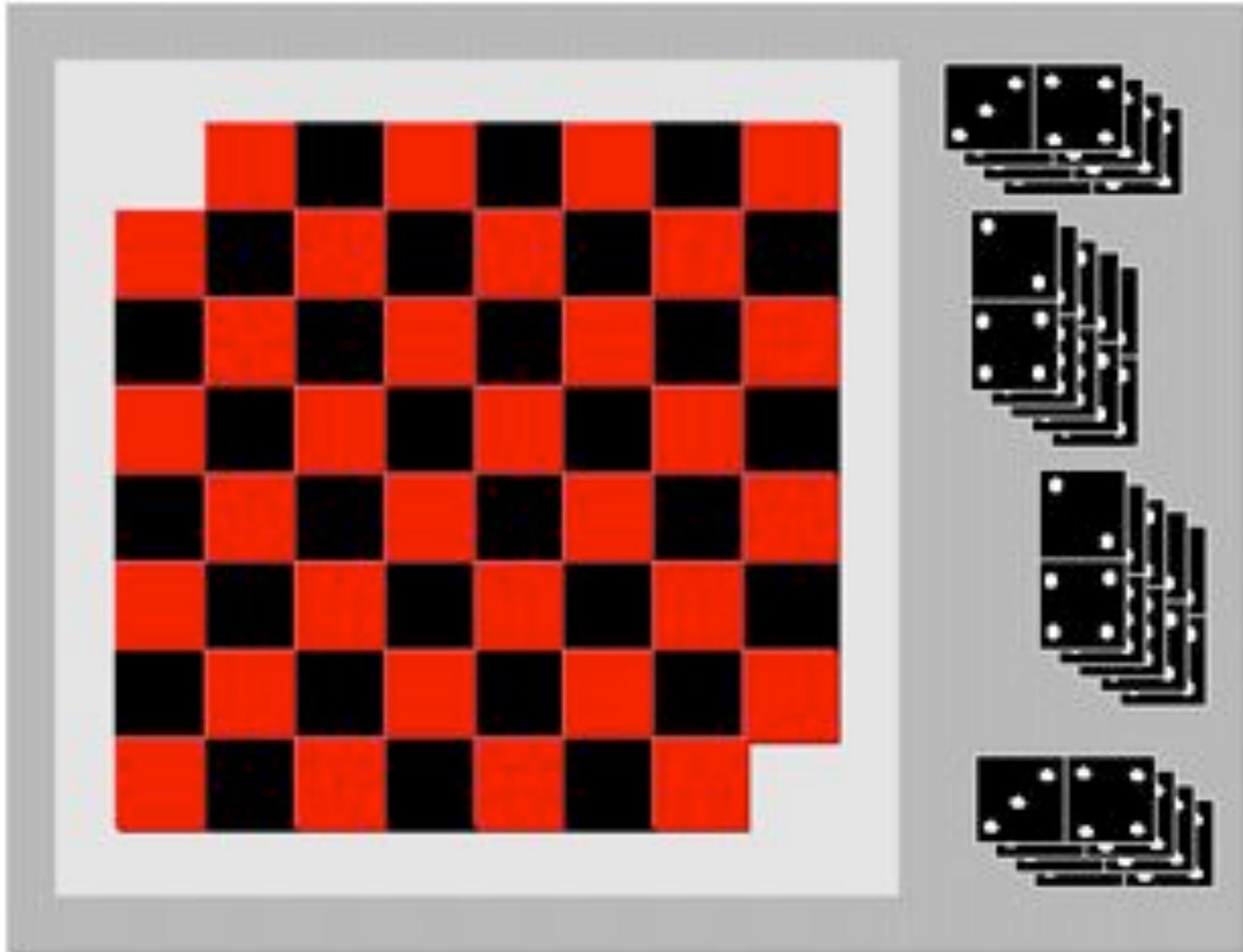
visualization makes a BIG difference (for human; for computer programs, Number Scrabble “is easier”)

2	7	6
9	5	1
4	3	8

Mutilated Matrix



Mutilated Chessboard



The Matchmaker Story

Many years ago, in a small but very proper village in the Midwest, there were 32 bachelors and 32 unmarried women. Through tireless efforts, the village matchmaker succeeded in arranging 32 highly satisfactory marriages. The village was proud and happy. Then one drunken Saturday night, two bachelors, in a test of strength, stabbed each other with knives.

Question: *Can the matchmaker, through some quick arrangements, come up with 31 satisfactory marriages among the 62 survivors?*

Constraints: good catholic environment — no same-sex marriages are allowed!

Existence of Powerful Visualization Tools is Not Good Enough

The Rationale for Critiquing Systems

♣ **color** ◇ Travis, D. (1991) *Effective Color Displays—Theory and Practice*, Academic Press, London:

“but when color is used inappropriately it can be very counter productive and few software designers have much experience with the use of color; the aim of this book is to synthesize our current knowledge in the area and specify guidelines so that programmers, engineers, and psychologist can use color.”

♣ **graphs** ◇ Kosslyn, S. M. (1994) *Elements of Graph Design*, W.H. Freeman and Company, New York

“one reason for the abundance of bad graphs is the proliferation of low-cost microcomputers and ‘business graphics’ packages which often seduce the user into producing flashy but muddled displays; many graphs are designed without consideration of principles of human perception and cognition”

The Scarce Resource: Human Attention, not Information

- ♣ **claim:** a design representation suitable to a world in which the scarce factor is information may be exactly the wrong one for a world in which the scarce factor is attention \diamond for example: a “good” representation captures the essential elements of an event, deliberately leaving out the rest
- ♣ **Herbert Simon:** *“What information consumes is rather obvious: it consumes the attention of its recipients. Hence a wealth of information creates a poverty of attention, and a need to allocate efficiently among the overabundance of information sources that might consume it.”*

Beyond Anywhere, Anytime, Anyone



The ‘Right’ Information at the ‘Right’ Time, in the ‘Right Place’,
in the ‘Right Way’, to the ‘Right’ Person

- ♣ **‘right’ information:** relevant to the task at hand ◇ task modeling
- ♣ **‘right’ time:** intrusiveness (pull versus push), interruptions
- ♣ **‘right’ place:** location-aware cell phone (noisy environment versus movie theatre), smart tour guides
- ♣ **‘right’ way:** multimodal presentation (textual, **visual**, auditory, tactile)
- ♣ **‘right’ person:** taking background knowledge and interests of specific users into account ◇ user modeling, “who do I ask and who do I tell”

Quality Dimensions of External Representations Supporting Distributed Intelligence

- ♣ long lasting (not ephemeral)
- ♣ easily produced, modified, and reproduced
- ♣ communicable over distance
- ♣ computational capabilities (e.g., multi-model, dependent on user, task, and context)
- ♣ exploiting the strength of the human system \diamond sometimes visualization make a big difference (Number Scrabble and Tic-Tac Toe) and sometimes they do not (Mutilated Matrix, Chessboard, and Match Maker Story)

Tools for Living and Tools for Learning

- ♣ **tools for living:** grounded in a “distributed intelligence” perspective, in which intelligence is mediated by tools for achieving activities that would be error prone, challenging, or impossible to achieve
- ♣ **tools for learning:** grounded in a “scaffolding with fading” perspective leading to autonomous performance by people without tools
- ♣ **the fundamental question:** what does it mean to learn in the 21st century in which powerful tools are available for many intellectual activities? (allowing people to have instant access to facts, assisting people in spelling, doing arithmetic, and performing numerous other intellectual activities)
- ♣ a potential danger ◇ **over-reliance on tools for living:** does an over-reliance on tools for living lead to *learned helplessness and deskilling*, ruining humans’ native abilities by making them dependent on tools?

Over-Reliance on Tools for Living

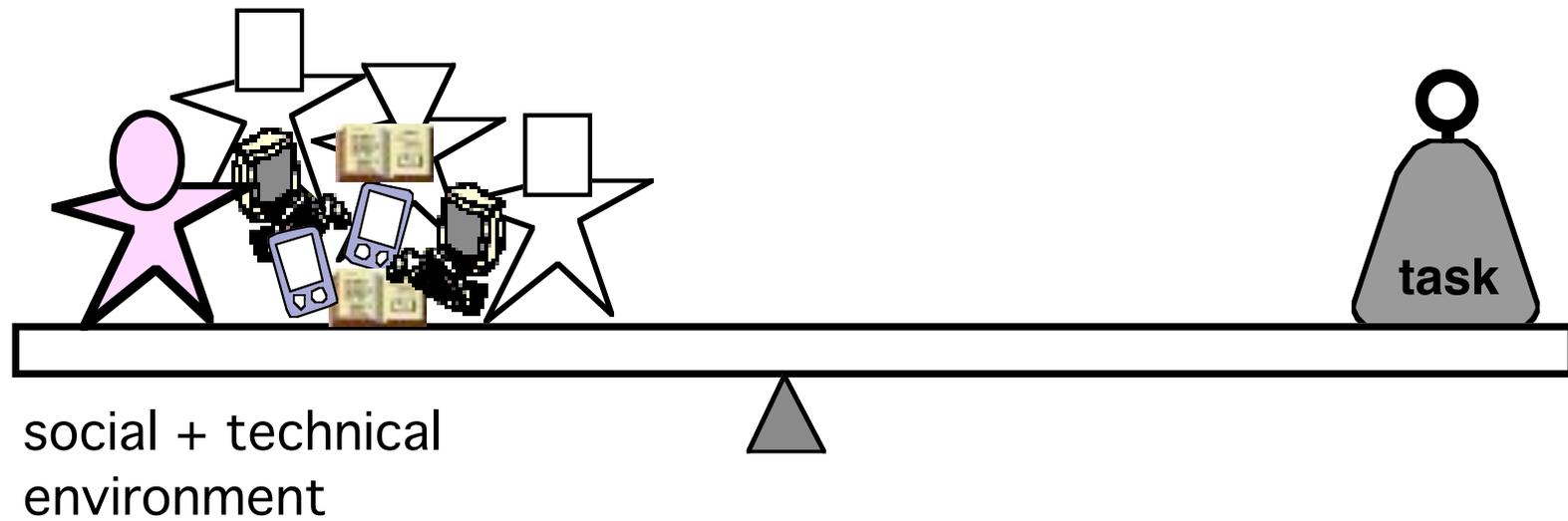


Over-Reliance on Tools for Living



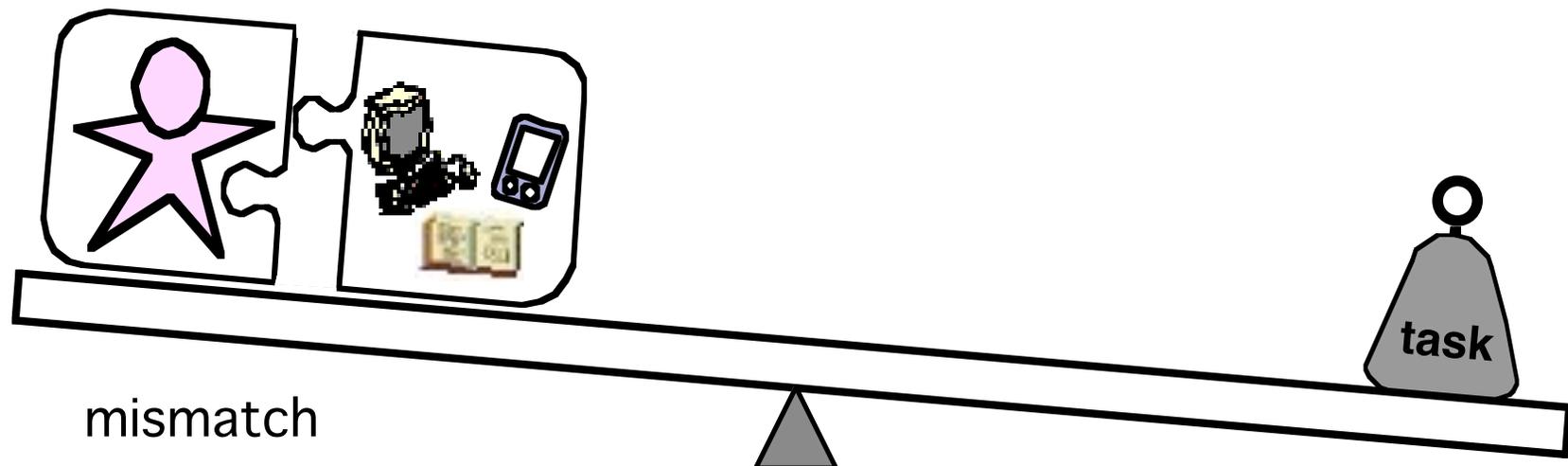
"Nurse, get on the internet, go to SURGERY.COM, scroll down and click on the 'Are you totally lost?' icon."

Collaborative Minds with Rich Tool Sets



Mismatch between Needs and Support Tools

- ♣ in the past: technology needed to fit **people's body**
- ♣ today: distributed intelligence approaches need to fit **people's mind and activities**



Two Examples of Socio-Technical Environments Supporting Distributed Intelligence

♣ **CLever**: Cognitive Levers — Helping People Help Themselves

♣ **EDC**: Envisionment and Discovery Collaboratory

Cognitive Levers: Helping People Help Themselves (CLever)

- ♣ to support people with cognitive disability by increasing their **independence**
- ♣ new insight into **distributed intelligence** by identifying new relationships between external and internal scripts
- ♣ creating '**eye glasses**' for the mind to demonstrate that anatomy does not need to be destiny
- ♣ **application areas**: human-centered public transportation systems, smart care, life histories
- ♣ **related paper**: Alexander Reppenning and Andri Ioannidou: *"Mobility Agents: Guiding and Tracking Public Transportation Users"*
- ♣ more info: <http://l3d.cs.colorado.edu/clever/index.html>

Envisionment and Discovery Collaboratory (EDC)

♣ the EDC supports:

- collaborative design
- integration of problem framing and problem solving
- social creativity (“learning when the answer is not known”)
- meta-design (design for designers)

♣ the EDC is based on:

- reflection-in-action
- creating shared understanding in communities
- allowing all stakeholders to act as informed participants and active contributors
(◇ a **Web 2.0** environment)

♣ the EDC has been applied to:

- urban planning
- emergency management

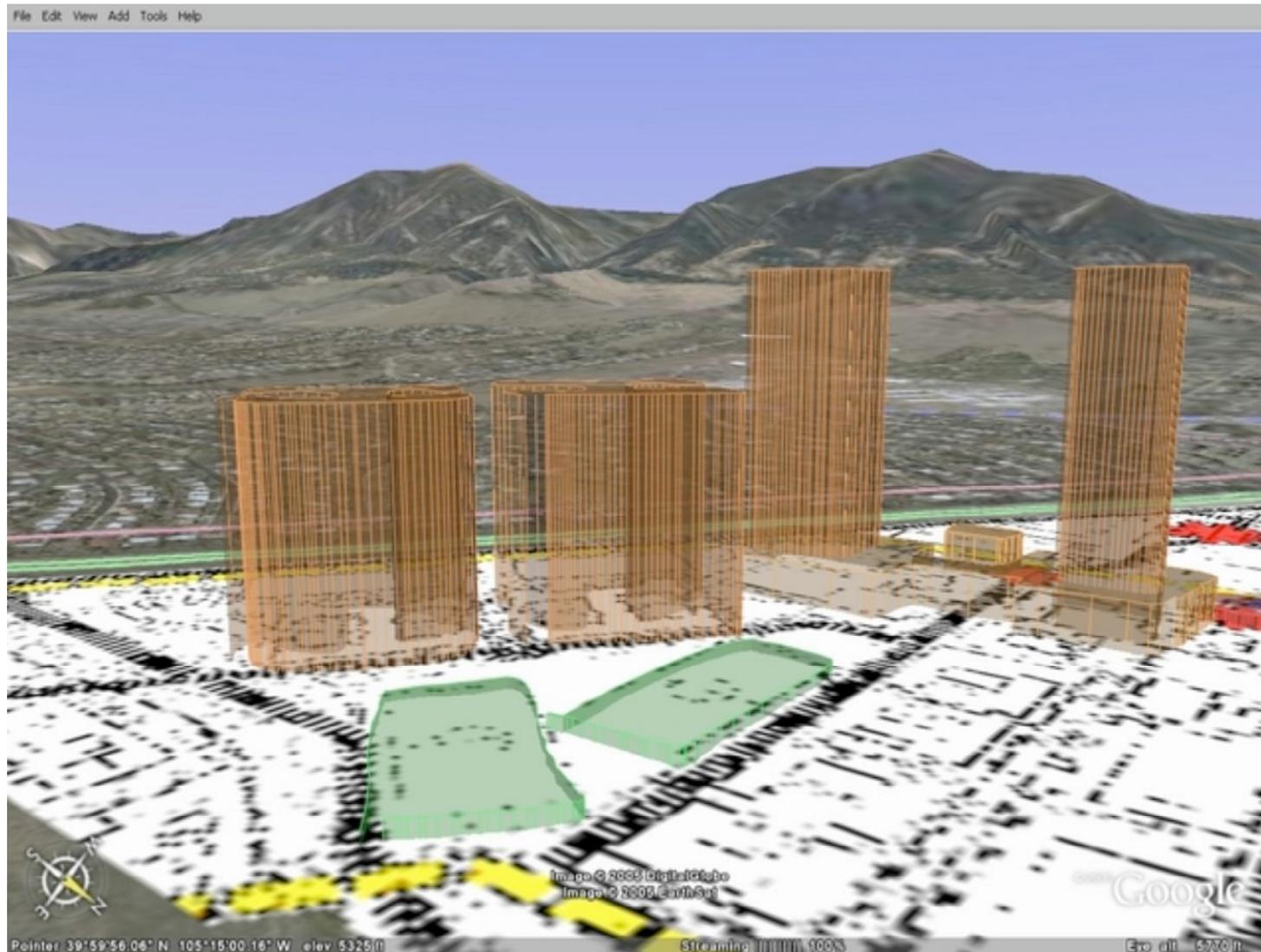
EDC: Integrating Action and Reflection Spaces



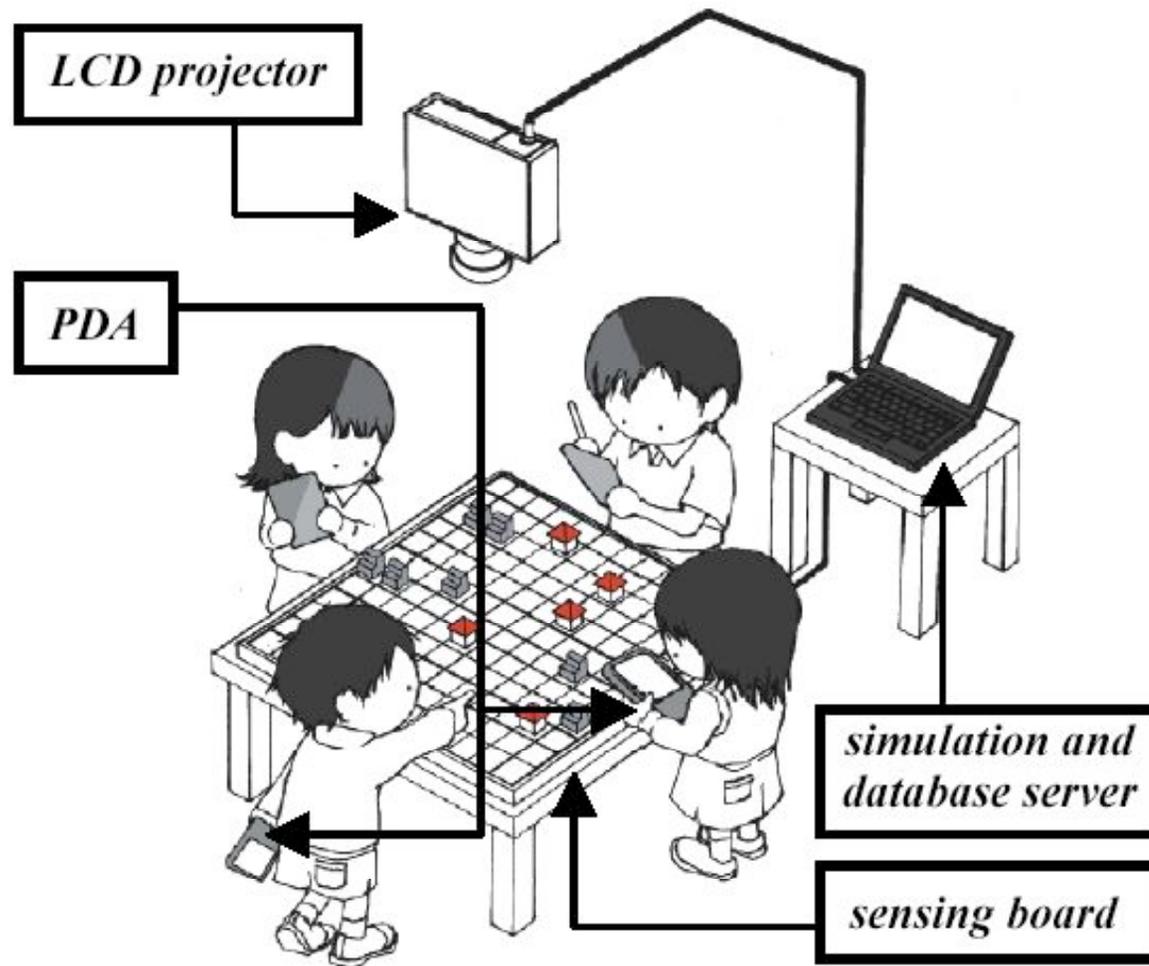
Application Context – Emergency Management: **Flooding**



Buildings Sketched into a Google-Earth Client



Integrating Individual and Social Creativity: **Caretta** (collaboration with Masanori Sugimoto, University of Tokyo)



Challenges and Questions for the Future

Looking 10 Years in the Future



first AVI conference
GUI

WWW
computational power
rich content
mobile technologies

new levels of
distributed
intelligence

Impact of New Technologies and New Media

- ♣ **claim:** all important technologies are “**Faustian bargains**”: they give and take away ◇ technological change always produces winners and losers

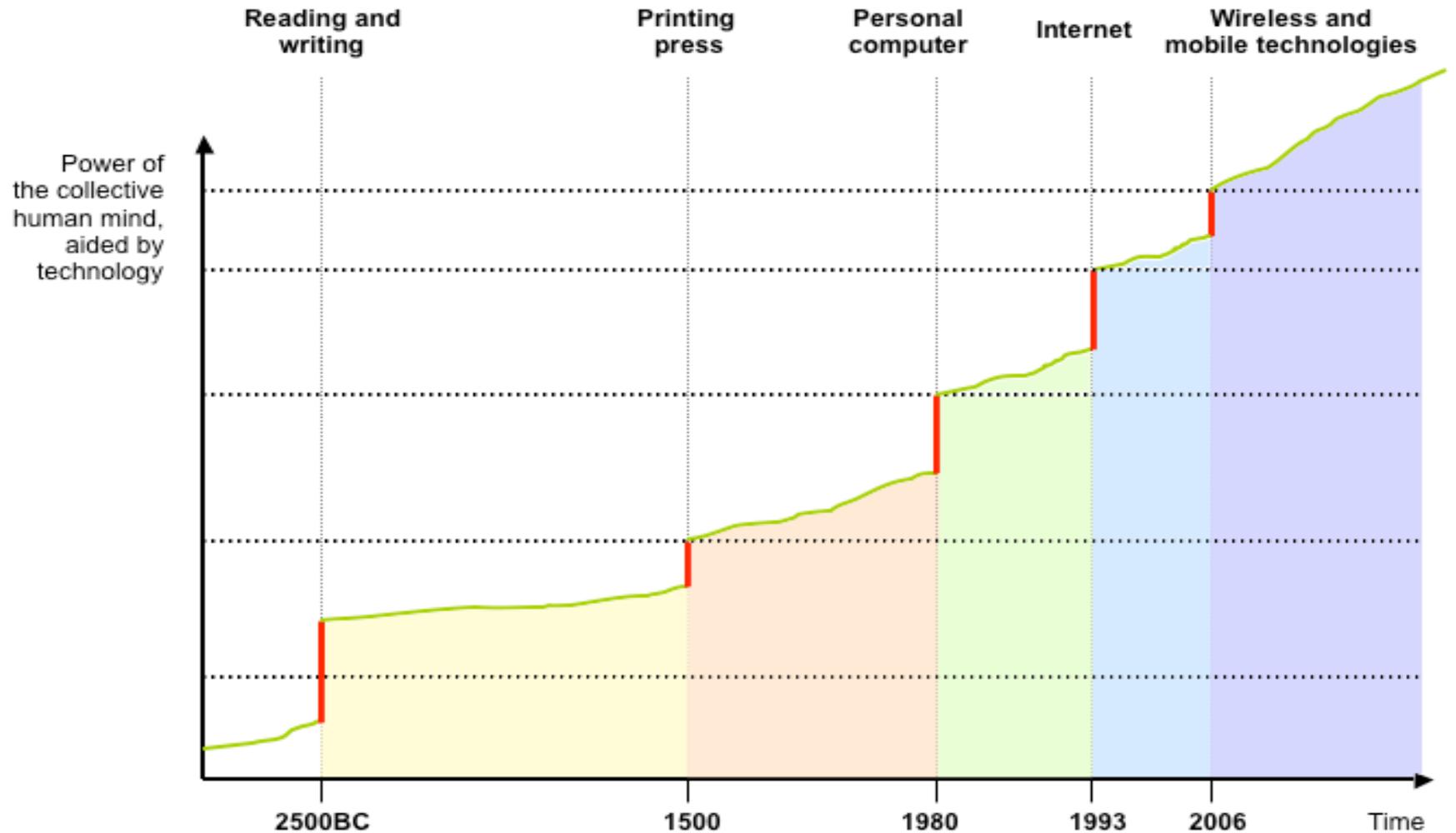
- ♣ while the growth of technology is certain, the **inevitability of any particular future is not** ◇ therefore: we can envision a number of different futures that might be

- ♣ the **visions** for possible futures (see Florida, R. (2002): “The Rise of the Creative Class”)
 - **techno-utopians** romanticize the future ◇ things will be wonderful with new technologies, technology will liberate us
 - **techno-pessimists** glorify the past ◇ technologies will oppress us
 - **basic belief:** the deep and enduring changes of our ages are not technological but social and cultural

New Media as “Faustian Bargains”

Medium	Strengths (Gains)	Weaknesses (Losses)
reading and writing	external memory	“books will destroy thoughts” (Sokrates)
slide rule	simplification of arithmetic operations	limited set of operations
punch cards computing	writing programs	large overhead
personal computer	personal	location bound
wireless and mobile technologies	always with us and always on; learning on demand; support in situated activities	disruptive; loss of introspection and reflection
visualizations	exploit the strength of the human visual systems	they are not universally applicable ◊ they are on tap, not on top

Beyond the Unaided, Individual Human Mind



Danger of a Decrease in the Power of the Aided, Collective Human Mind

- ♣ “Amusing Ourselves to Death” with **irrelevant information** (Postman)
- ♣ **continuous partial attention** and the attention economy (“always on”: constantly being accessible makes someone inaccessible)
- ♣ a live black-berry, a switched-on mobile phone or a laptop in front of someone is an admission that her/his **commitment to the current activity** is limited

A Science of Design

(a new research program of the National Science Foundation)

- ♣ identify **contextualized “sweet spots”** in the numerous design trade-offs
- ♣ develop criteria and requirements which **form of distributed intelligence** is appropriate for the people involved, the task at hand, the objectives to be achieved
- ♣ create new **conceptual frameworks** and innovative **socio-technical environments** to support **distributed intelligence**

Conclusions

♣ the future is not out there to be discovered — it has to be **invented and designed**

♣ **where are we?**

“This is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.” —Winston Churchill