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Cognitive Science and Technology Perspective on Human-Systems Interaction

Dr. Chris Forsythe
Distinguished Member Technical Staff
Cognitive and Exploratory Systems and Simulation
Sandia National Laboratories

Where human-machine systems are today

- Basic science of human performance > human factors engineering guidelines
- Design processes and methods for testing and evaluation
- User modeling/profiling, is it a convenience or a threat?
- Advanced interface technologies filling their respective niches, eg VR

The current path promises many years of <u>incremental</u> improvement in human-computer interaction

People are drowning in data

Only 1.6×10^{-9} of data bombarding the operator used in real time!

Source: Steinbuck, 1962

Estimates of Human Processing Capabilities

Filtering Algorithms

Process	Flow (Bits/Sec)	% Filtered	% Orig. Filtered
Sensory	1 Billion		--
Neural Coding	3 Million	0.003	--
Cognitive	16	0.000005	.0000000016
To Perm. Store	0.7	0.04	.0000000014

A TV quality movie every second → Sensory

A high resolution photo every second → Neural Coding

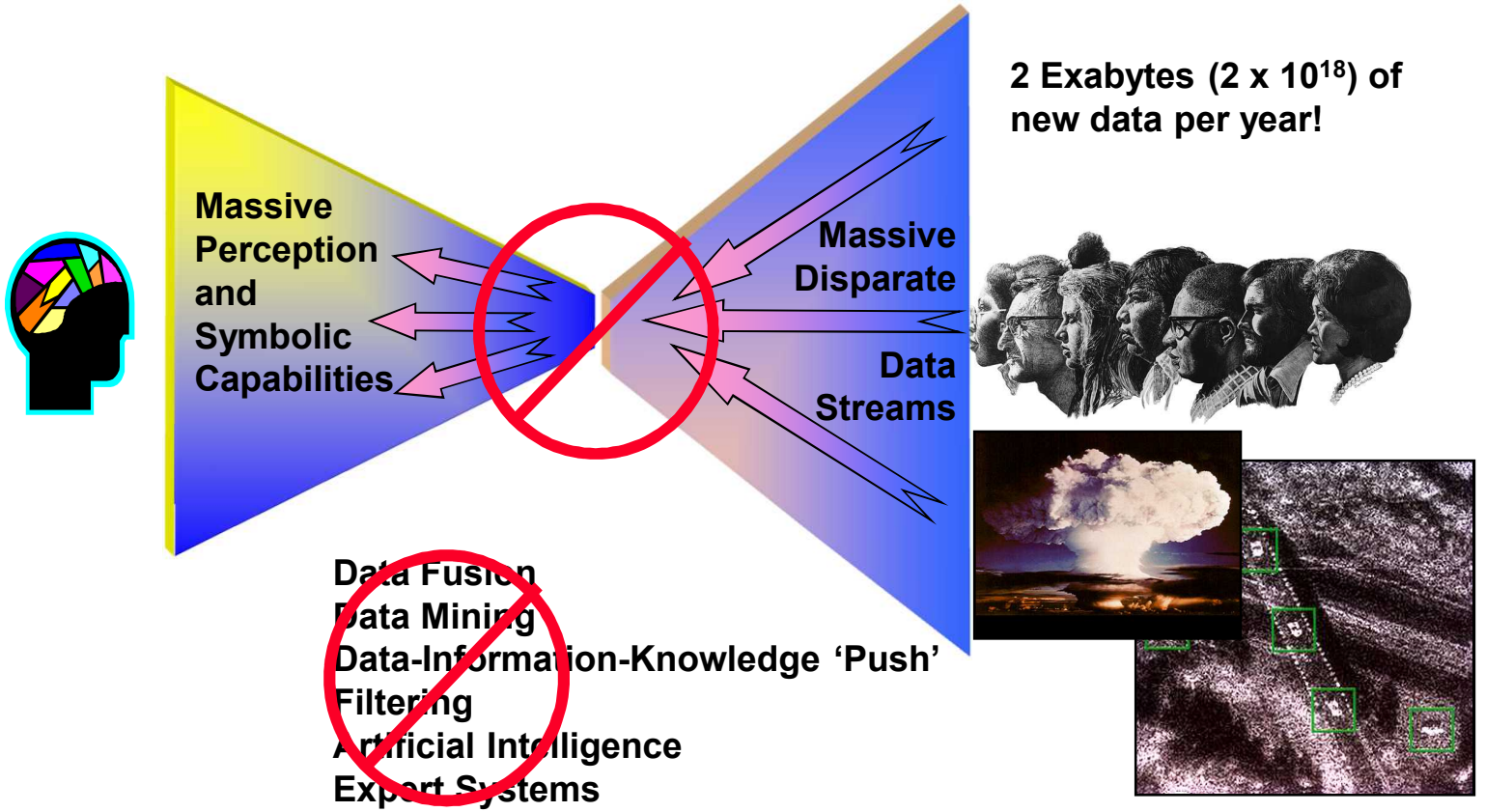
Two words every second → Cognitive

One character every second → To Perm. Store

Total volume of information generated worldwide annually = 2 Exabytes
Exabyte [1,000,000,000,000,000,000 bytes OR 10^{18} bytes]

Sources: *Lyman and Varian, How Much Information?, 2000; and Schmorrow, Augmented Cognition, 2000.*

More of the same has not worked



The technology meant to solve the problem has made the problem worse
-- human strengths have been disabled!

Fundamentally rethink the human-machine interface

NOT redesign Human-Machine Interfaces, yet again

The challenge is to learn to swim in a sea of information

Cognitive systems offer the needed paradigm shift

- Embed within machines **individualized** computer models of cognitive processes vital to human communication, cooperation and collaboration.
- Provide software that **acquires accurate models of an individual's knowledge** of a domain or task by observing their day-to-day system interactions.
- **Create systems that interact with users in a knowing cognitive manner:**
  - (1) know what you know, what you don't know, what you do, how you do it,
  - (2) can place current events in the context of past experiences and
  - (3) make readily accessible the knowledge and experience of diverse experts.

Transform the human-machine interaction to become more like an interaction between two cognitive entities

The Neuro/Cognitive Revolution is upon us and it will be disruptive

- Digital Revolution

Maturing – probably another 10 years of progress

Biggest impacts are being realized right now

- A few still to come – medicine, security, governance

- Bio Revolution – early stages

Beginning to realize some impacts

Biggest impacts are 10-30 years out

- NanoTech Revolution – early stages

Realizing some impacts in nano-materials and simple devices

Biggest impacts are 15-20 years out

- Neuro/Cognitive Revolution – very early stages

First impacts are in demo/test now

Significant impacts in less than 10 years [large capital investment not required]

Biggest impacts yet unknown

- Multi-disciplinary Revolution

Will happen in parallel to the others

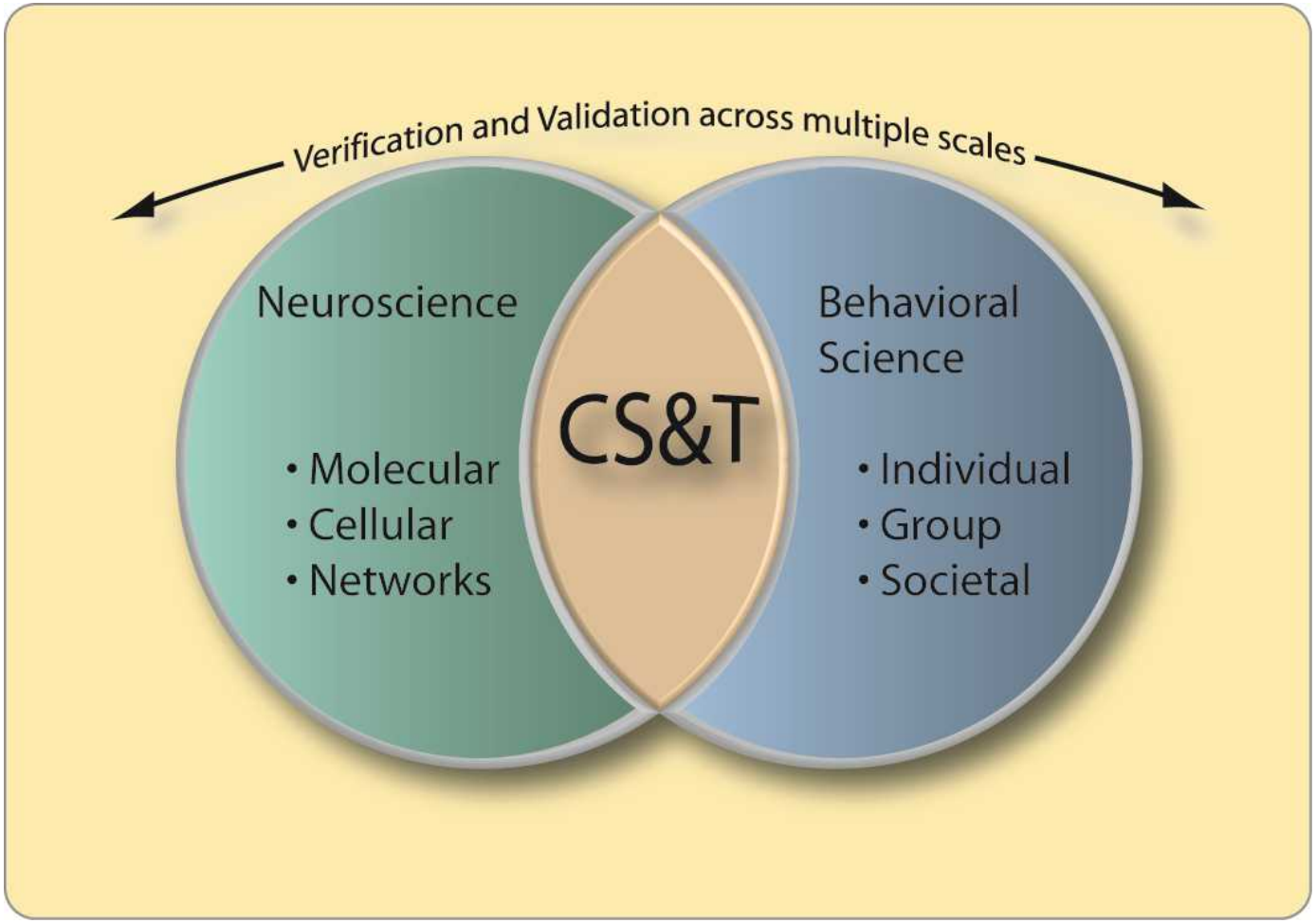
Will be the source of greatest impact

From "Neuro and Cognitive Futures" by Michael Swetnam, CEO & Chairman Potomac Institute for Policy Studies

Changes are on the horizon that will make the paradigm shift brought about by the GUI seem modest in comparison

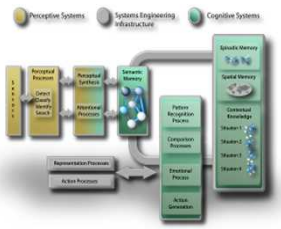
Cognitive Science and Technology has been targeted as core competency of Sandia

CS&T exists at the Intersection of Neuroscience and Behavioral Science



Cognitive framework and automated knowledge capture provide basis for integrated products

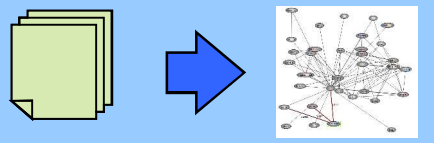
Cognitive Framework



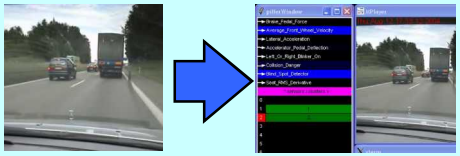
Generic cognitive engine employed with each product

Automated Knowledge Capture

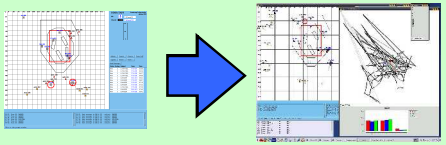
Text Sources



Machine Transactions

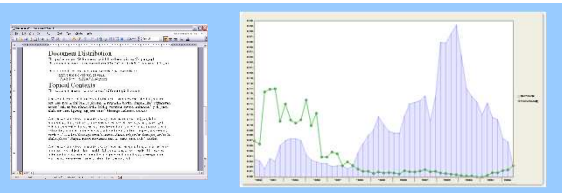


Spatial Domains

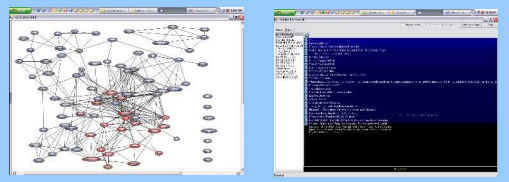


Acquire model of individual through observation of everyday activities

CS Products

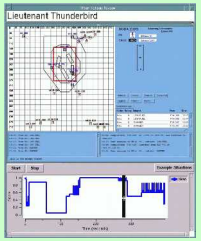


Understand the Model



Use the Model

Dynamic Adaptation

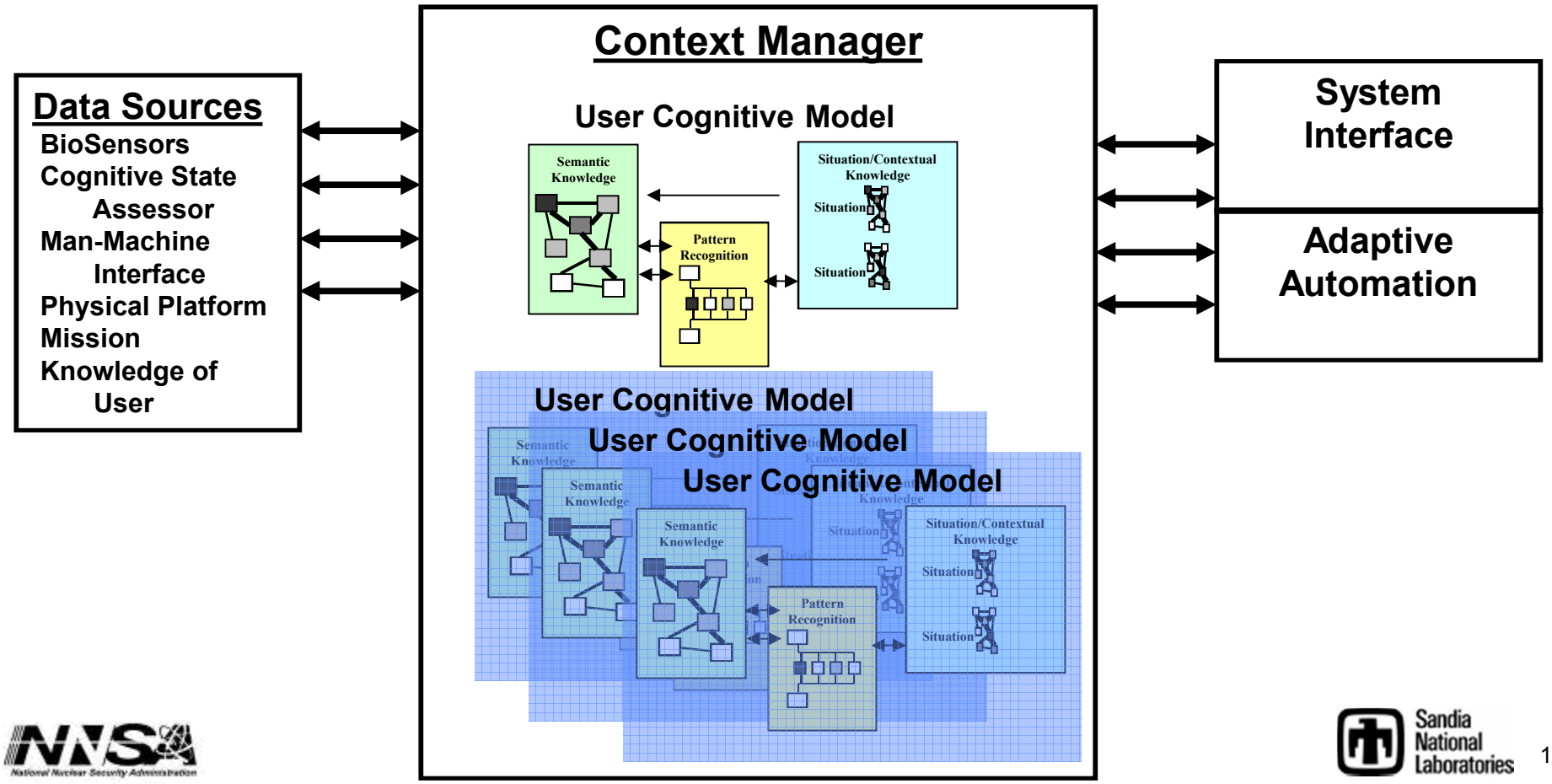


Automated After Action Review

Simulation Human Behavior

A conceptual depiction of a system to infer and adapt to a user's ongoing cognitive processes

Context Manager utilizes <u>real-time</u> user cognitive model(s) to infer context and provide basis for adaptation.



Variations on the basic system concept

Data sources

- user actuation of controls
- eye-tracking and pupillary response
- user head position
- user postural adjustments
- physiological recordings
- physical location (e.g. GPS) and associated intelligence
- system state variables
- external sensors
- communications
- user response to structured queries

Types of context

- user tasks and goals, including relative urgency and progress toward goals
- user awareness of stimuli or events
- user situation interpretation, or misinterpretation
- user emotional state
- impediments to normal cognitive functioning
- user knowledge of domain or task(s)
- user skill levels or capabilities
- actual and/or perceived physiological state
- perceived roles and responsibilities
- awareness of others

System adaptations

- adjust rate of information flow
- adjust time profiles of automated systems
- adaptive automation and/or allocation of tasks
- adjust saliency of information display elements
- system alerts
- augmented context recognition and interpretation
- user-tailored system support
- adaptive training

Human analogs to a context manager

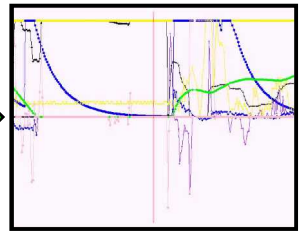
- Recognize a person is encumbered > hold door, offer to carry some of the load.
- Recognize a person is confused > alter or expand explanation, draw picture.
- Recognize a person does not recognize importance of what they are being told > shift emphasis in speech, state importance.
- Recognize a person does not see something > alert them to where to look, point or turn the person.
- Recognize a person does not remember > offer cues to prompt their recall.

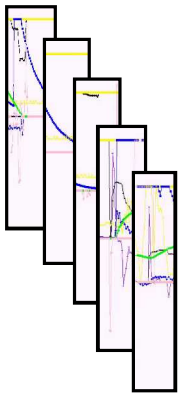
We can create a model customized to an individual through observation of their machine transactions

The Sandia cognitive modeling framework provided the foundation for technology to model automotive driving contexts.

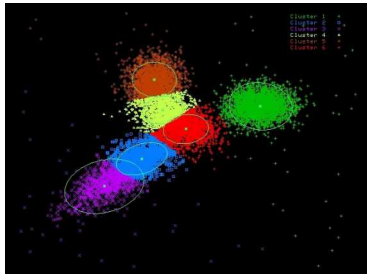
Wheel speed
Steering
Brake pedal
Accelerator
Distronic

Data Profile Across Time



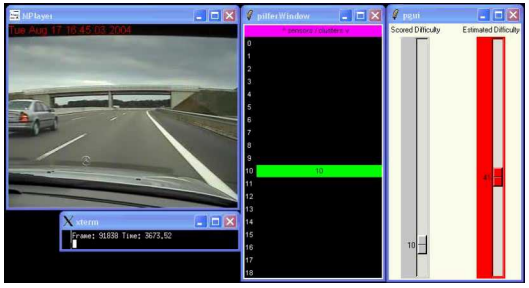


Cluster analysis of data from time windows



Clusters specified as contexts for real-time context recognition

Contexts provide basis for model that predicts driving difficulty



Results

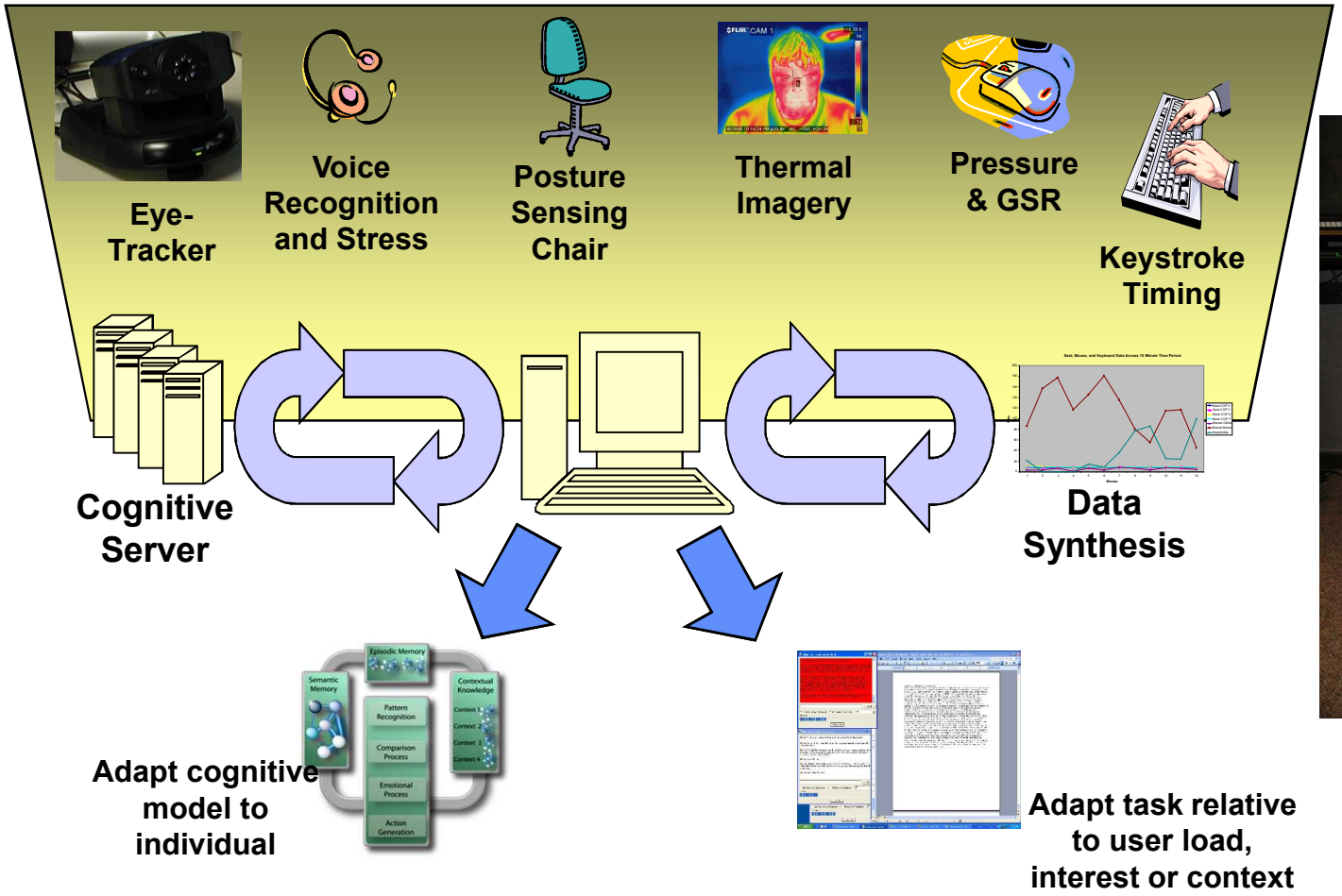
- **Median L1 test-set error: 1.28%**
- **Test-set mitigation agreement: 93.17%**

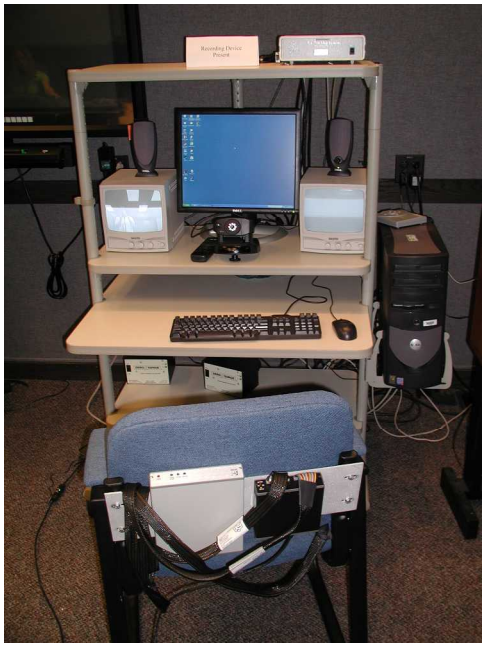
NNSA National Nuclear Security Administration

Sandia National Laboratories

A suite of non-intrusive sensors provides basis for real-time adaptation

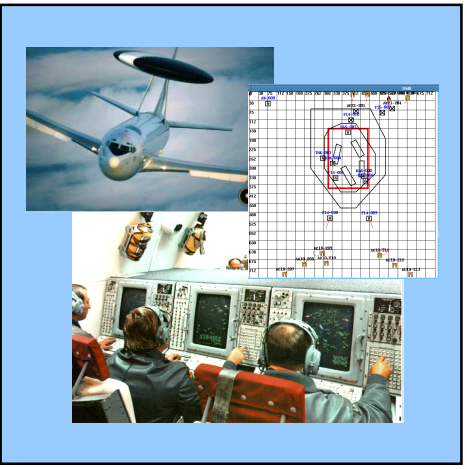
An extensible framework synthesizes data from non-intrusive cognitive state sensors for enhanced models and adaptive systems.





Through observation of behavior in a spatial domain, we can model the knowledge of an individual

Actions taken as an individual directs entities in response to spatial features of the environment provide a basis for modeling their knowledge.



Observation

Features provided by environment

Time = 599
Plane1Pos = 34, 58
Plane1Fuel = 2051

Feature Extraction

Features derived from observations

VelocityPlane1=200
DistancePlane1to2=1.4
OrientationPlane1to2=1234

Retrospection (Salience, Prediction)

Features weighted on basis of importance and significance of consequent events

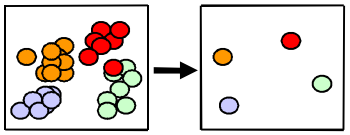
W_1 * VelocityPlane1
W_2 * DistancePlane1to2

Context Similarity

Compute Euclidian distance between observations

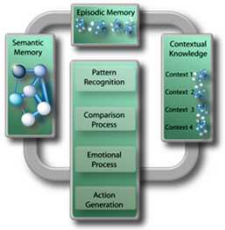
Generalization

Discard redundant and retain distinct observations



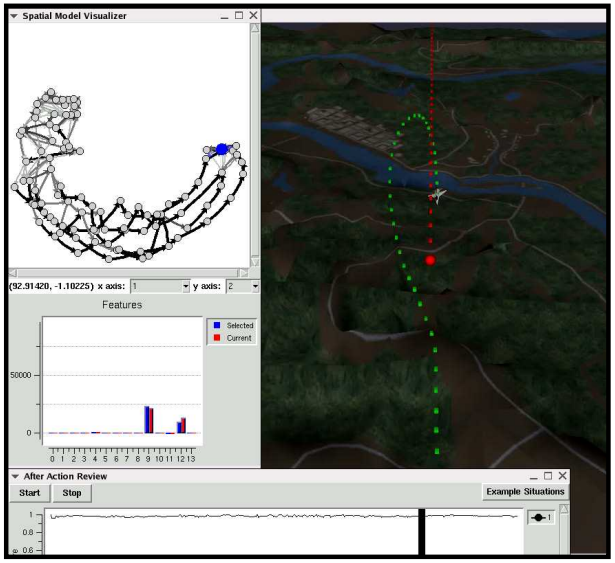
Contexts (Knowledge Base)

Model of individual

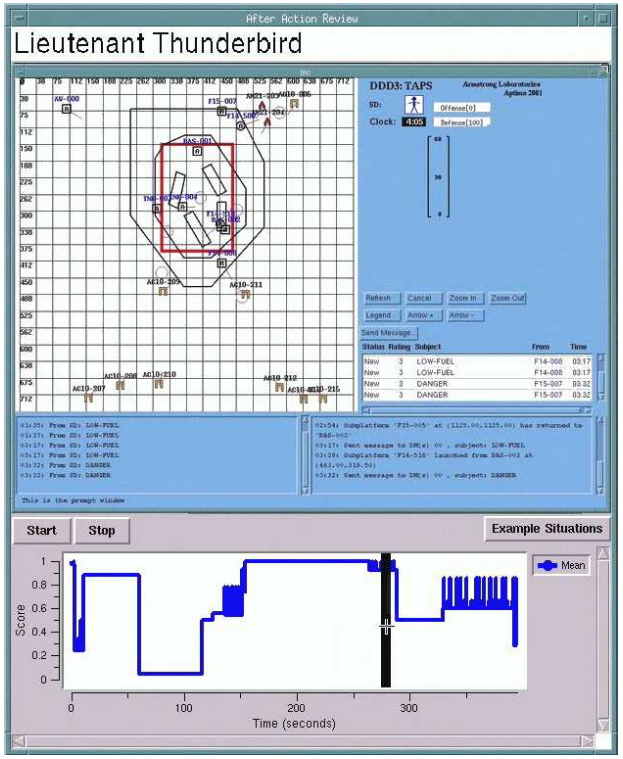


Automated after action review reduces resource requirements necessary to support effective training

As trainee performs tasks, their performance is compared to cognitive models of experts to identify discrepancies



Upper left figure illustrates performance of expert in aircraft stern convergence task and lower graph compares expert to trainee performance.



Lower graph illustrates performance of trainee relative to an AWACS expert over the course of training session.

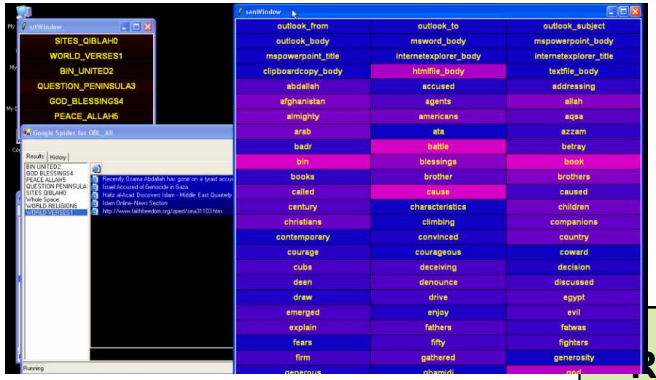
Where are performance deficiencies for which training interventions should be targeted?

How would an expert perform within comparable situations?

What is the trainees overall proficiency with the task?

An individual's response is assessed by presenting documents to their cognitive model

Users present documents to a cognitive model, or use a cognitive model to spider the web or archival records.



Cognitive model spiders the WWW to find relevant web pages.

Report on Model Bill Clinton and Document State of the Union Address of Thomas Jefferson

Sandia Analyst Aide
Tuesday, August 16, 2005

Report automatically generated for response of model to a document.

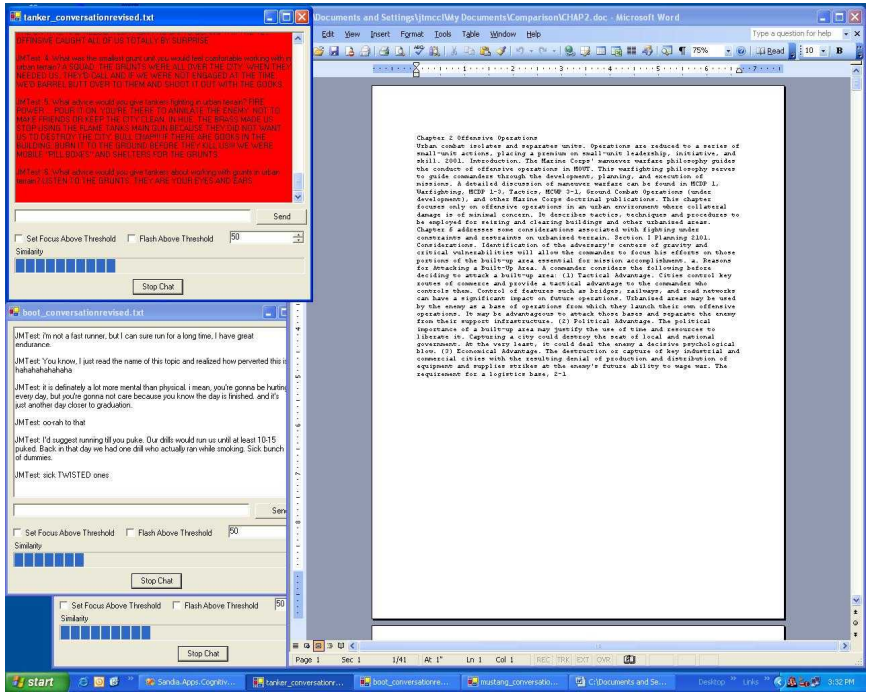
How would an individual respond to certain ideas, facts or events?

Which documents, websites, postings, etc. contain ideas and statements consistent with a certain individual?

Where are the similarities and differences between my thinking and that of another individual?

Individual information bandwidth is expanded through attentive systems utilizing cognitive models

Individual's cognitive model monitors multiple data sources to highlight transactions of interest or relevance to the current task.



Operator cognitive model monitors multiple Instant Messaging windows and alerts operator when it detects an item of interest or relevance to the primary task.

Which events would I find interesting or relevant to me?

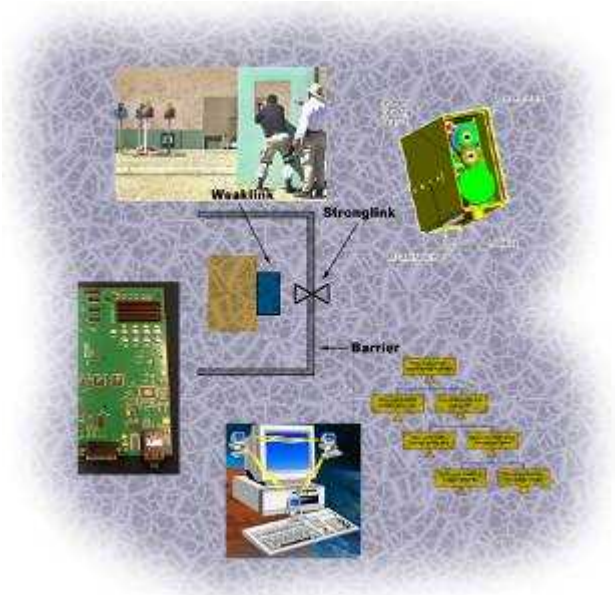
Which events are relevant to the task(s) I am currently performing?

Do I need to interrupt my activities to attend to an incoming message?

Surety of Cognitive Technologies:

Essential enabling technologies for CS&T success

Leverage expertise in Surety S&T to enable application of CS&T to problems that demand the highest levels of safety, security and reliability.



Integrated Capabilities

- Methods for vulnerability analysis
- Test and evaluation facilities and expertise
- Encryption and authentication for secure exchange of sensitive information
- Red Teaming for systems assessment
- Surety concepts and technologies for high consequence applications

Surety concepts and technologies are essential for the safety, security, reliability and validity of CS&T.

Technologies introduced by CS&T push the boundaries of current ethical and legal policies

Key issues likely to arise illustrate why we must be proactive:

- Who retains custody and control of an individual's thoughts once they are shared with a cognitive agent?
- How far does the right to privacy apply, and for whom does it provide protection?
- Could the technology either intentionally or unintentionally shift distributions of power?

Ethics must be considered now as cognitive systems are currently being developed

- Unforeseeable impacts on lives
- Societal concerns must be recognized as technology advances
- Minimal precedence within science and technology history

Discussion