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Keynote Presentation:

Integrating Humans with Software and Systems: Technical Challenges and a Research Agenda

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Information is not a scarce resource. Attention is.

- Herbert Simon, 1991

Presentation Outline

- System Trends
- Operational Context
- Evolving Human Roles
- Human Limitations
- Exemplar HSI Problems
- HSI Principles
- Future HSI Research
- Summary

System Trends

- Increasing size and complexity
- Increasing need for flexible capabilities that can be adapted in operational environment
- Continuing use of legacy components/subsystems
- Demand for rapid fielding

These trends are expanding the role of humans in systems.

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Operational Context

- Unpredictable dynamic environment
- Kinetic and non-kinetic operations
- Rapidly evolving asymmetric threats
- Need for adaptive response
- Need for ongoing tradeoffs

Evolving Human Roles

- From that of an **operator** outside the system to that of an **agent** within the system
  - decision maker
  - supervisor with override authority
  - re-assignable participant (peer, assistant)

These human roles pose new challenges to human systems integration.

Human-Systems Integration

- A **multidisciplinary** field
  - spans manpower, personnel, training, human factors engineering, system safety, personnel survivability, health hazards, and habitability
- A **comprehensive management and technical strategy** – to achieve robust human-system performance in dynamic, uncertain operational environments

The key is to capitalize on the strengths of humans, software, and systems while circumventing their limitations.

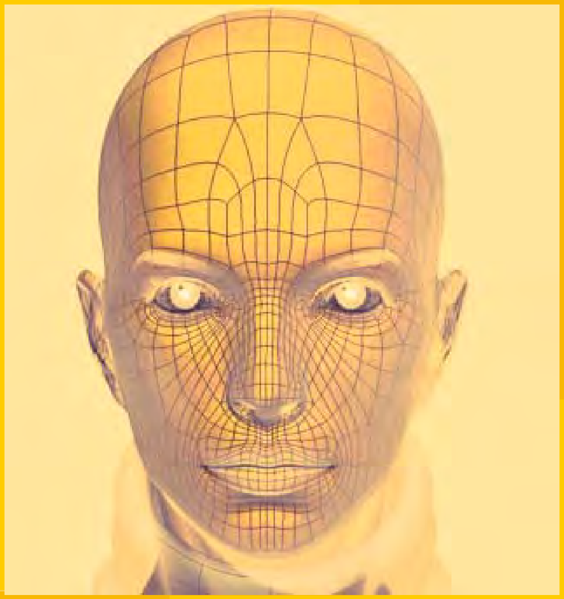
Systems Engineering Mindset

- Humans are **suboptimal job performers** that need to be shored up and compensated for
- This mindset **fails to capitalize on human ingenuity** and creativity
- It leads to **inherently incompatible systems** relative to human conceptualization of work
- The resulting mismatch inevitability creates **human reliability issues** that show up as **human error**

Human systems integration strategies need to capitalize on human ingenuity and creativity while circumventing human limitations.

Human Limitations

- Multitasking / Context switching
- Rare event monitoring
- Rapid adaptation
- Cognitive overload
- Attentional capacity saturation
- Decision making under stress
- Risk Homeostasis



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Multitasking Findings

- Experiments conducted at Stanford University
  - compared high multitaskers to low multitaskers
- Research Questions
  - can high multitaskers filter information as well as low multitaskers?
  - do high multitaskers have better memory recall ?
  - do high multitaskers context switch faster ?
- Findings
  - high multitaskers had great **difficulty filtering out irrelevant information** (prone to distractions)
  - high multitaskers had greater **difficulty recalling** (couldn't compartmentalize)
  - high multitaskers had great **difficulty context switching** (couldn't separate contexts)

Sometimes can accomplish more by doing less.

Multitasking is the art of distracting yourself from things you'd rather not be doing by doing them simultaneously.

Context Switching

- Occurs when humans are interrupted during task performance
- Interruptions during tasks that require high level of concentration can prove quite costly
  - up to 15 minutes to restore same concentration levels afterwards

Need to minimize context switching through selective task automation and by limiting sources of interruption.

Rare Event Monitoring

- When monitoring low probability high consequence events, human vigilance tends to drop (Yerkes-Dobson Law)
- This can frequently cause humans to miss their occurrence producing dire consequences

Such tasks are best left to automation and alerting mechanisms.

Rapid Adaptation

- Adaptivity is a unique human capability that is neither absolute or perfect
  - humans do adapt, BUT… not quickly
  - it is imperative that scope of adaptation be narrow
- System decomposition can achieve narrow adaptation goals
- Rate at which humans adapt varies with type of change (e.g., information channels, language, C^2 patterns, architectural configurations)
- Satisfying human adaptivity needs can give rise to human reliability issues
  - tradeoff between adaptation rate and human error likelihood and rate
  - need to define what is acceptable error rate

Need to be mindful of tolerable error rates when attempting to increase performance through adaptivity.

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Cognitive Overload

- Humans have cognitive limitations
  - limited working memory capacity for storing/manipulating information
  - human reasoning biased toward using stored knowledge and patterns
- Under sustained cognitive overload
  - humans tend to adapt their cognitive strategy (e.g., sacrifice performance on secondary task; shed tasks)

Decision aiding can help with offloading humans as well as prioritizing tasks based on context.

Attentional Capacity Saturation

- When attentional demands exceed human attentional resources, performance inevitably suffers (e.g., miss detecting events)
- The clinical Model of Attention (i.e., focused, sustained, selective, alternating, divided attention) is helpful in evaluating attentional demands
- Kahneman's Attention Theory is especially relevant
  - level of arousal determines attentional capacity of humans
  - allocation policy takes into account stable demands and momentary intentions

Need to maintain near-optimal level of arousal to ensure maximum availability of attentional resources.

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Decision Making Under Stress

- Humans required to deal with **large number of factors in short time frame**
- Iran Air Flight 655 shot down by U.S. Navy cruiser Vincennes over the Persian Gulf – incident attributed to stress and ambiguity during decision making
- Stress can produce **"tunnel vision"** and impair decision making
- Interestingly, judgment is not always compromised by stress
- Under stress, humans tend to adopt a simpler mode of information processing that potentially helps with focusing on critical issues

Humans need training and decision aiding to ensure consideration of all factors and expansion of the available option space.

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Risk Homeostasis

- Humans exhibit a **target level of risk**
- Target level of risk is defined as "the **level of risk a person chooses to accept** to maximize the overall expected benefit from an activity."
- Wilde (1998) defines **risk homeostasis** as:

  "… the degree of risk-taking behavior and the magnitude of loss, due to accident and lifestyle-dependent disease, being maintained over time unless there is a change in the target level of risk."

Risk homeostasis can be overcome through rewarding safety and increasing cost of accidents to the person at fault.

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Exemplar HSI Problems

Exemplar HSI Problems

- Airline Crew Interruption
- Munich Taxicab study
- British Columbia Anti-Drunk Driving Campaign
- Metrolink Train Crash
- Automobile Blind Side Indicator

Airline Crew Interruption

- Northwest Airline crew was preparing to fly out of Detroit
- Crew began pre-flight checklist, but were interrupted by air traffic controller with new taxiing instructions and warning about wind shear
- After the crew finished talking to the controller, they did not resume going through checklist
- They took off without checking status of aircraft's flaps
- A flight emergency occurred shortly after takeoff because flaps were in wrong position
- Crew mistakenly interpreted the problem as wind shear and crashed the plane (NTSB 1988)

Crew failed to resume going through checklist post-interruptions.

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Munich Taxicab Study

- Half the taxicab fleet was equipped with antilock breaking system (ABS); the other half had older brake systems

- ABS-equipped drivers started taking more risks
- This behavior left their "target risk level" unchanged
- Non-ABS drivers drove the same way as before

Accident rate with and without ABS was the same – risk homeostasis.

British Columbia
Anti-Drunk Driving Campaign

- Government campaign in the late 1970's
- Reduced accident rate associated with DUI by nearly 18% over a 4-month period
- However, accidents caused by other factors increased 19% during the same period; why?
- People started taking more risks on the road leaving "target risk levels" unchanged

Reduction in DUI-related accidents saw a corresponding increase in accidents due to other factors – risk homeostasis.

MetroLink Train Crash

- MetroLink train crashed into Union Pacific freight locomotive … ran four lights
- Sanchez, the engineer (driver), didn't hit brakes before the L.A. train crash
- Teenager reported receiving a text message from Sanchez a minute before collision
- Explanations offered:
  - engineer (driver) was distracted while texting (human error)
  - engineer was in the midst of an 11 ½ hour split shift when he ran the first red light (fatigue)
  - radio communication breakdown between engineer and conductor (comm disruption)
  - engineer suddenly stricken ill (health issue)
  - sun glare may have obscured engineer's view of signals (environment factor)
- Main Reasons:
  - system was not designed for integration with human (assumed a perfect human)
  - Sanchez was doing a split shift (tired); also multi-tasking - - - he was error-prone

Both systemic design flaws and human error responsible for crash.

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Blind Side Indicator

- A decade ago, a blind side indicator was developed for cars
- It was designed to tell if someone was in the driver's blind side
- This **device was never approved**, allowed, "put into play;" why?
  - behavioral research predicted that, people were going to over-use the indicator, and not bother looking over their shoulder … an undesirable change in behavior

Indiscriminate introduction of new technology can potentially change human behavior, and not necessarily for the better.

HSI Principles

- Ensure manageable task-related **cognitive load**
- Ensure that **systems do not have to adapt faster** than humans can
- Minimize incidence of **frequent context switching and multi-tasking** through proper task assignment and design of task flow, and selective/partial task automation
- Maintain **human-system interaction** at a level that keeps human sufficiently engaged without being cognitively overwhelmed
- Ensure consistent, **predictable system response**
- **Make systems inspectable** so humans are not forced to make assumptions (often erroneous) about system state

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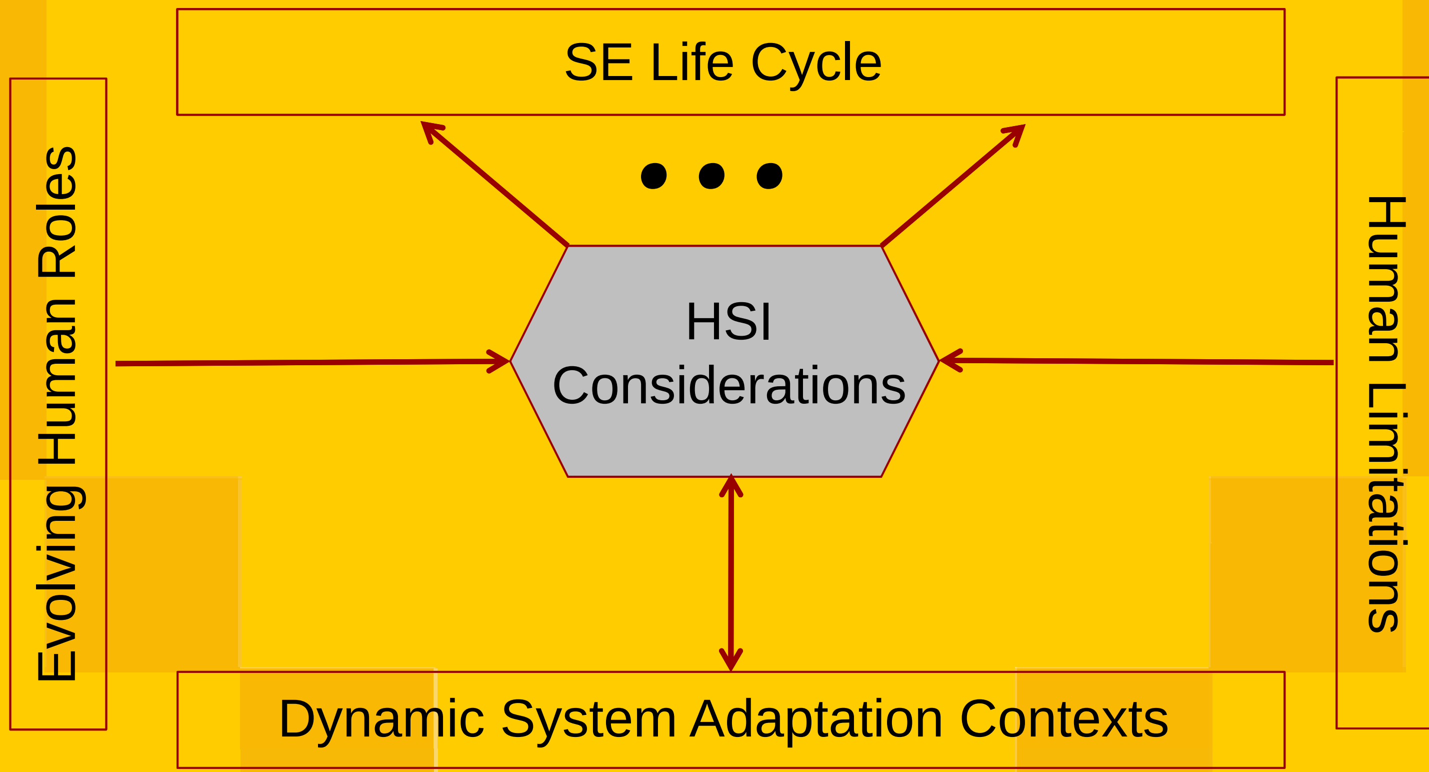
Future HSI Research



HSI methods need to address human limitations, evolving human roles, dynamic system adaptation contexts, and the full SE life cycle.

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Research Questions

- What are the circumstances in which **humans are able to adapt** readily, slowly, or not at all?
- How does **stress affect human's ability** to assimilate and apply new information?
- How does sustained **cognitive overload** modify human behavior and performance?
- What are the **different aspects of humans** that need to be addressed in HSI?
- Where and how should **HSI considerations** be addressed in the system/software life cycle?

Research Questions (cont'd)

- What **system problems** can be addressed through appropriate HSI strategies?
- How should research findings in human performance (e.g., adaptivity, decision making under stress, ….) be reflected in **HSI strategies**?
- What are the **architectural implications** of incorporating humans in different capacities within complex systems?
- How can **HSI strategies inform and guide** the development of flexible automation for adaptable systems?
- How can **understanding of human cognitive strategies** be used to design decision aiding and performance support systems?

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Recommendations

- **Consolidate findings from currently fragmented research** findings in human performance within a human performance knowledge base
- **Transform findings into HSI guidelines** for developing adaptive/adaptable systems
- **Develop methods, processes, and tools** that incorporate HSI guidelines
- **Introduce HSI methods, processes, and tools** to systems and software engineering communities in a manner that clearly conveys their value proposition

Integrating findings from the fragmented human performance research base is a prerequisite to achieving robust human-system performance.

Summary

- **Systems continue to grow** in size and complexity
- Systems designed for **long-lived operation** need to be able to adapt to changing/emerging operational needs
  - continually **changing threats** and environmental factors
  - evolving human roles
- System adaptivity is upper-bounded by tolerable **human error rate**
- For robust human-system performance
  - need for human to **multitask and context switch** needs to be minimized
  - automation should be used to **monitor and flag rare events** and **aggregate information**
  - **human cognitive strategies** under overload condition needs to be understood for effective design of decision aiding and performance support systems
- Human-system integration considerations should be brought to bear **early and throughout** the systems engineering life cycle

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