Mapping Complexity Sources in Nuclear Power Plant (NPP) Domains

Farzan Sasangohar[1], Kristopher Thornburg[1], M. L. Cummings[1], Amy D'Agostino[2]

[1]Massachusetts Institute of Technology

[2]Nuclear Regulatory Commission

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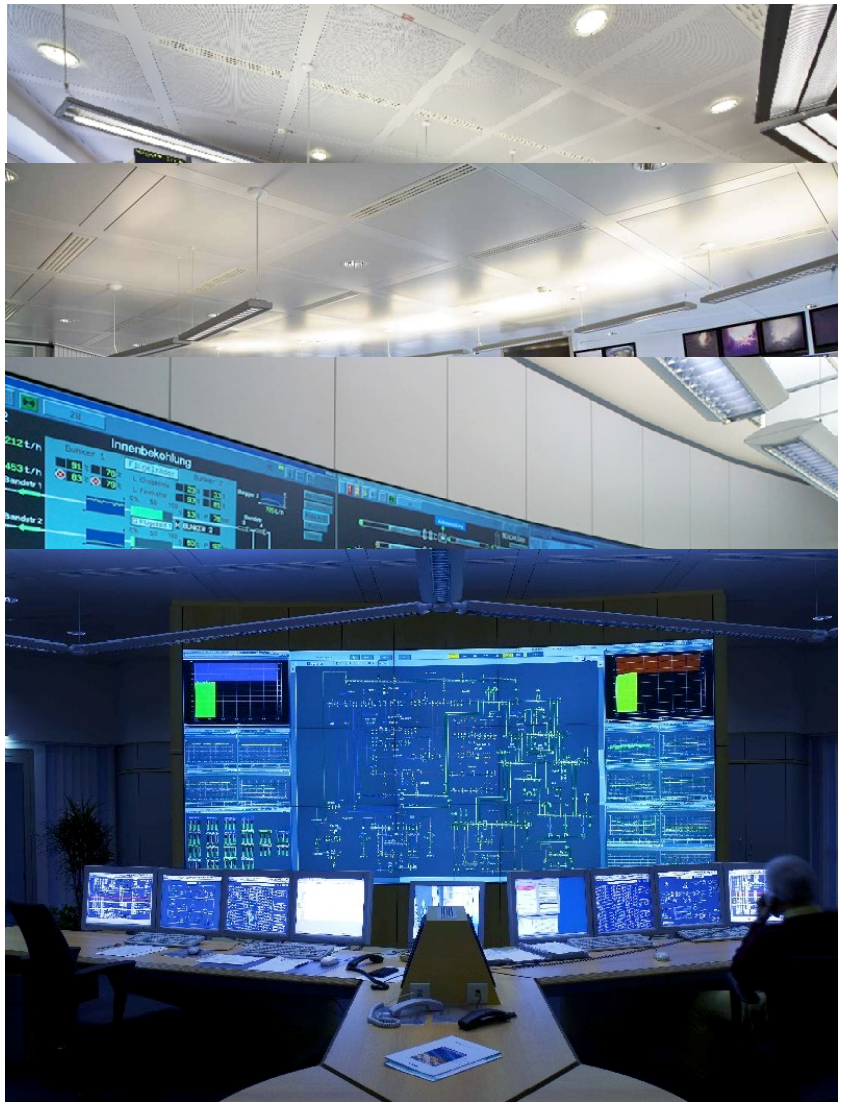
ADVANCED CONTROL ROOMS



Source: http://www.mauell.co.uk/gallery/control-room/

New power plants will contain advanced digital control rooms

- Increased automation
- Increased dynamic information to display
- Different type of info presentation
- Different type of interaction

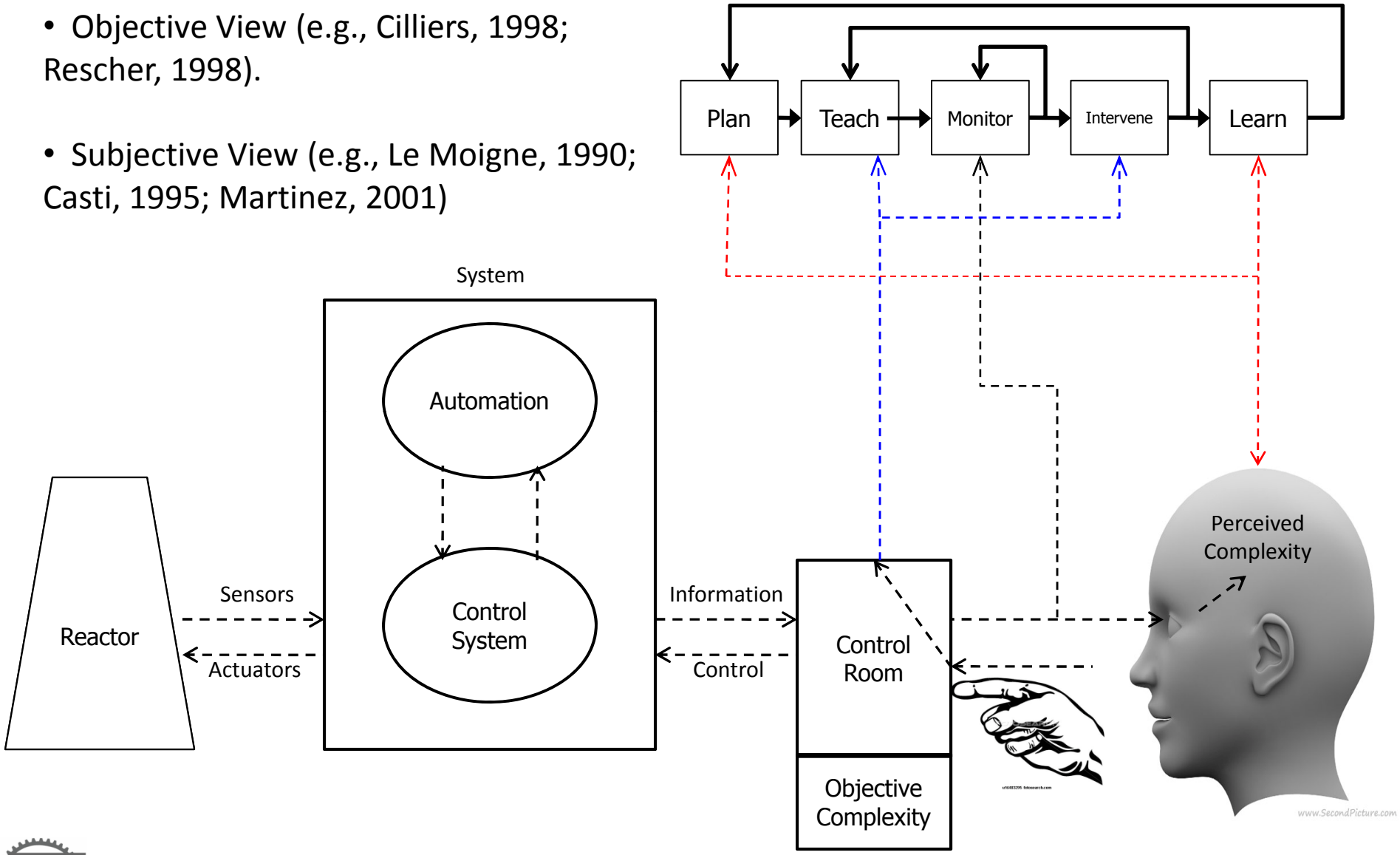
Human cognitive abilities unchanged

How will this affect Perceived Complexity?

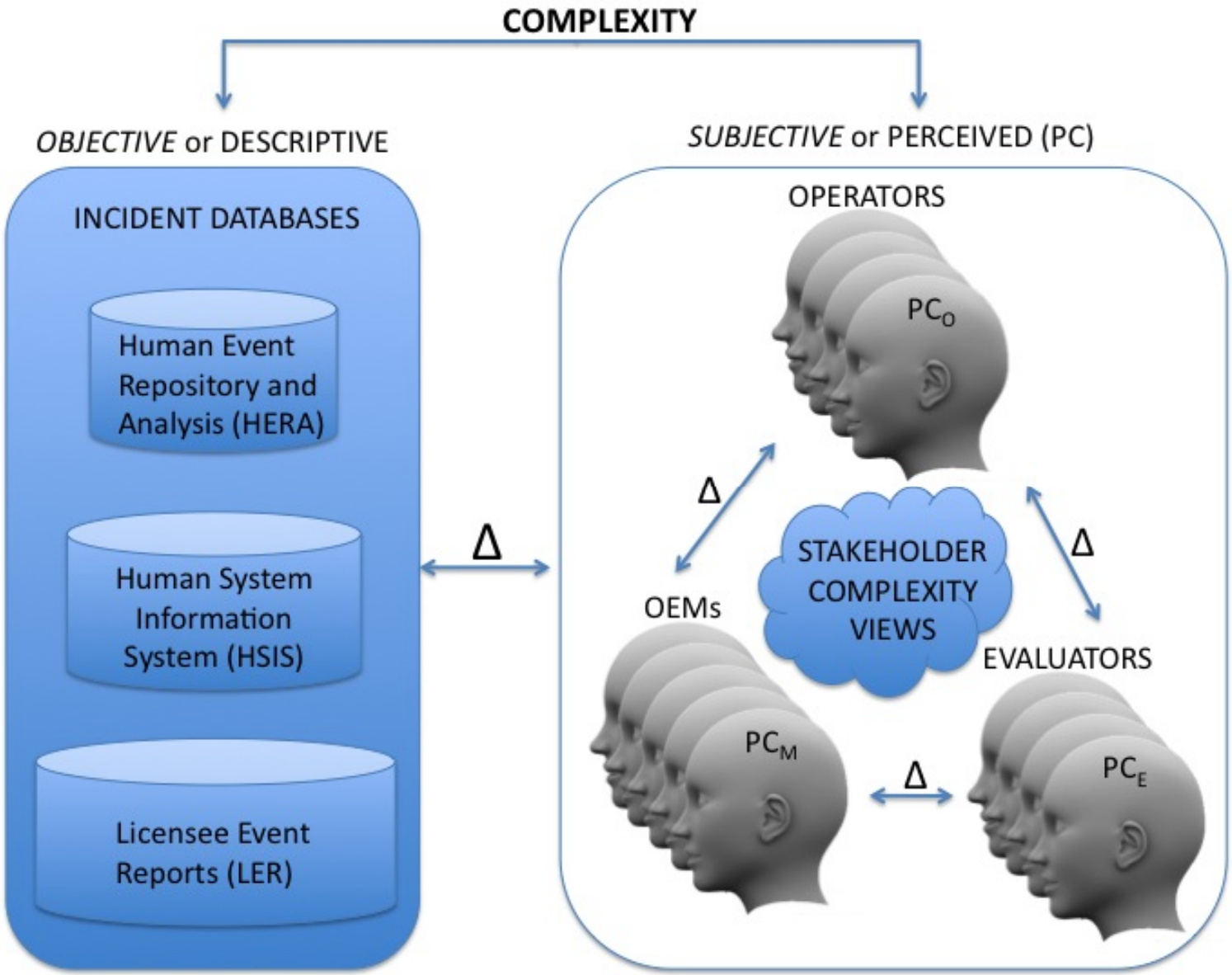
BACKGROUND

- Objective View (e.g., Cilliers, 1998; Rescher, 1998).

- Subjective View (e.g., Le Moigne, 1990; Casti, 1995; Martinez, 2001)



SUBJECTIVE VS. OBJECTIVE COMPLEXITY



RESEARCH QUESTIONS

1

How should complexity be defined in the context of NPP control rooms? In other words, what factors contribute to the complexity of a control room?

2

How can the effects of complexity on human performance be measured both objectively and subjectively, while still considering the difference between the two?

3

How can the negative effects of complexity in NPP control rooms be mitigated or changed through design, procedures and organizational practices?

METHOD: IDENTIFYING SOURCES OF COMPLEXITY

Physical Environment	
• Control room size • Too many external interruptions	• Control room layout • Ambient noise level

Organizational Factors	
• Team unfamiliarity • Shift length	• Inadequate procedures • Inadequate simulator training • Inadequate communications

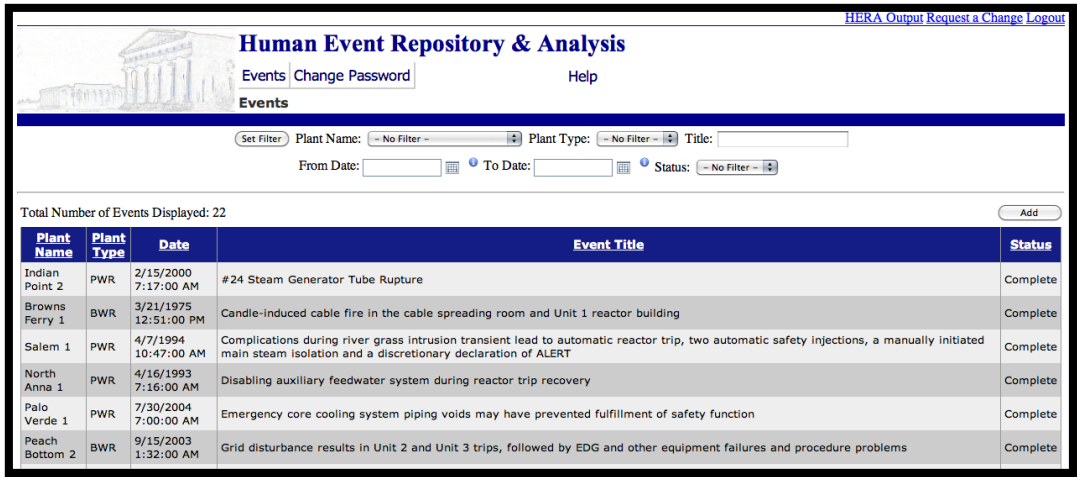
Task Factors	
• Time constraints • Too few operational mode transitions • Too many operational mode transitions • Frequency of operational mode transitions	• Too few crew members available • Too many crew members available • Too few items on turnover sheet • Too many items on turnover sheet • Amount of required unit conversions

Human System Interface (HSI)	
• Too few HIS panels • Too many HIS panels • Variety of HIS panels • Panel too small • Panel too large • Too few redundant panels • Too many redundant panels • Variety of colors used for functional groupings • Clutter (in displays or panels) • Volume of information (in displays or panels) • Too few alarms • Too many alarms	• Too few control devices • Too many control devices • Variety of control devices • Too few redundant control devices • Too many redundant control devices • Too few control devices shared by different systems • Too many control devices shared by different systems • Variety of alarms • Amount of inoperable equipments • Amount of malfunctioning equipments

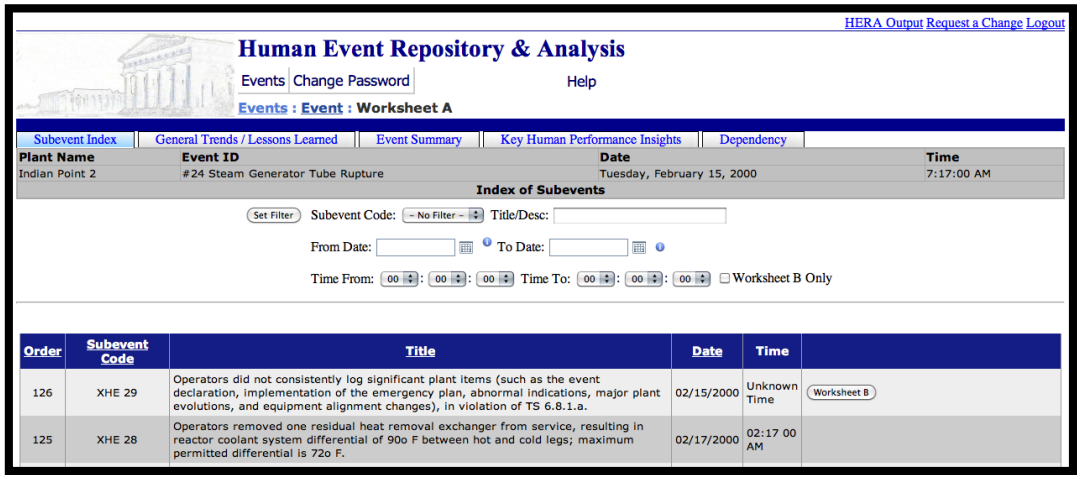
Procedural Factors	
• Too few procedures • Too many procedures • Inadequate procedures • Too few concurrently used procedures • Too many concurrently used procedures • Conflicting procedures • Variety of procedures • Level of assessment effort	• Too few steps in procedures • Too many steps in procedures • Amount of check points • Too few crew members required to execute procedure • Too many crew members required to execute procedure • Too few information sources to make an assessment • Too many information sources to make an assessment

Cognitive Complexity	
• Years experience in same control room • Experience in other control rooms	• Boredom • Cognitive fatigue • Stress

METHOD: HUMAN EVENT REPOSITORY & ANALYSIS (HERA)



Plant Name	Plant Type	Date	Event Title	Status
Indian Point 2	PWR	2/15/2000 7:17:00 AM	#24 Steam Generator Tube Rupture	Complete
Browns Ferry 1	BWR	3/21/1975 12:51:00 PM	Candle-induced cable fire in the cable spreading room and Unit 1 reactor building	Complete
Salem 1	PWR	4/7/1994 10:47:00 AM	Complications during river grass intrusion transient lead to automatic reactor trip, two automatic safety injections, a manually initiated main steam isolation and a discretionary declaration of ALERT	Complete
North Anna 1	PWR	4/16/1993 7:16:00 AM	Disabling auxiliary feedwater system during reactor trip recovery	Complete
Palo Verde 1	PWR	7/30/2004 7:00:00 AM	Emergency core cooling system piping voids may have prevented fulfillment of safety function	Complete
Peach Bottom 2	BWR	9/15/2003 1:32:00 AM	Grid disturbance results in Unit 2 and Unit 3 trips, followed by EDG and other equipment failures and procedure problems	Complete



Plant Name	Event ID	Date	Time
Indian Point 2	#24 Steam Generator Tube Rupture	Tuesday, February 15, 2000	7:17:00 AM

Order	Subevent Code	Title	Date	Time	
126	XHE 29	Operators did not consistently log significant plant items (such as the event declaration, implementation of the emergency plan, abnormal indications, major plant evolutions, and equipment alignment changes), in violation of TS 6.8.1.a.	02/15/2000	Unknown Time	Worksheet B
125	XHE 28	Operators removed one residual heat removal exchanger from service, resulting in reactor coolant system differential of 90o F between hot and cold legs; maximum permitted differential is 72o F.	02/17/2000	02:17 00 AM	

collect information for assessing human performance

22 Incidents

Index of sub-events (chronological sequence of equipment, human, and off-plant sub-events)

Dependencies

Information about specific human sub-events

METHOD: EVIDENCE-BASED APPROACH

HERA_complexitySourcesEvidenceSheet.xls

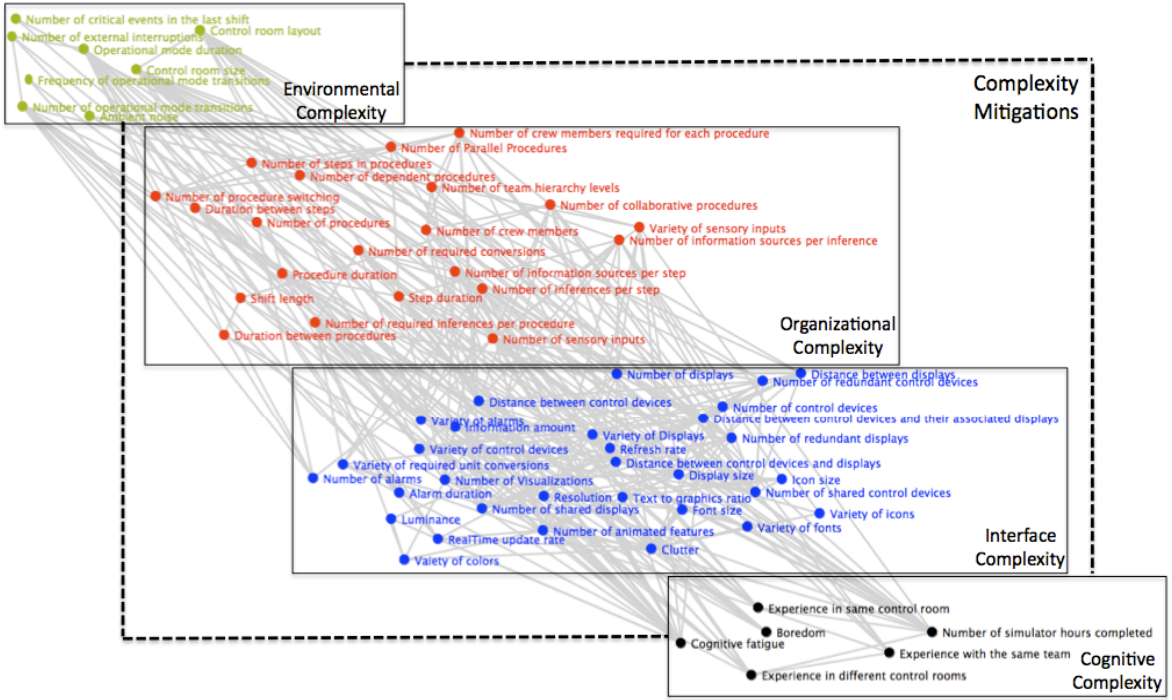
Sheets | Charts | SmartArt Graphics | WordArt

	A	B	C	D	E	F	G	H	I	
1		**HERA INCIDENTS**								
2		**Indian Point 2**	**Browns Ferry 1**	**Salem 1**	**North Anna 1**	**Palo Verde 1**	**Peach Bottom 2**	**Palo Verde 1-2**	**Diablo Canyon 1**	**Wol**
3	**Environmental Complexity**									
4	Control room size (1)			XHE14	HS3,10					
5	Control room layout (2)			XHE14	HS3,10				HS19	
6	* Available time (3)	HS2,4,5,6,7,8,10,13,15,19,21,23,27,28,30,31,32,33 XHE20,21,22,23,24,26,29	HS6,7,12,13,14,15,17,19,20,21 CI8,9 XEQ1,2,4,7,8,9,10,11,16,17,18 PS7,8	XHE13,14,17	XHE4,5,6 HS3,4		PS11,12		XHE1 HS2,26,27	XHE7,1 CI12
7	• Operational mode duration (4)									
8	Frequency of operational mode transitions (5)		XEQ1 EQA2							
9	Number of operational mode transitions (6)		XEQ1 EQA 2							
10	Number of critical events in the last shift (7)								HS18	XHE14
11	Number of external interruptions (8)		XHE23,24 HS2,3,4,5,8,10,12,13,14,17,20,21,22,23,27,28,29,30,31,32,33,37	XHE12,14,15,16,17,18,19 HS2 CI8 EQA5	HS3,6 CI4		CI2	XHE7,8,10,25,26 HS1,28,29,30 CI3 PS9,10	HS2,4,7,9,10 CI15	XHE12 CI14 PS3,4,19,22,7
12	Ambient noise level (9)									
13	**Organizational Complexity**									
14	Number of procedures (10)			XHE18,23 HS2,11,14,19,21,22 CI12	HS3,5,10,16 CI4	XHE8	HS8,11	XHE15,16,18,26,27,28,29,33 HS5,18		HS18
	Variety of procedures							XHE15,16,18,27,2		

Sheet1

Normal View | Ready | Sum=0 | SCRL | CAPS | NUM

METHOD: COMPLEXITY SOURCE NETWORK (CSN)



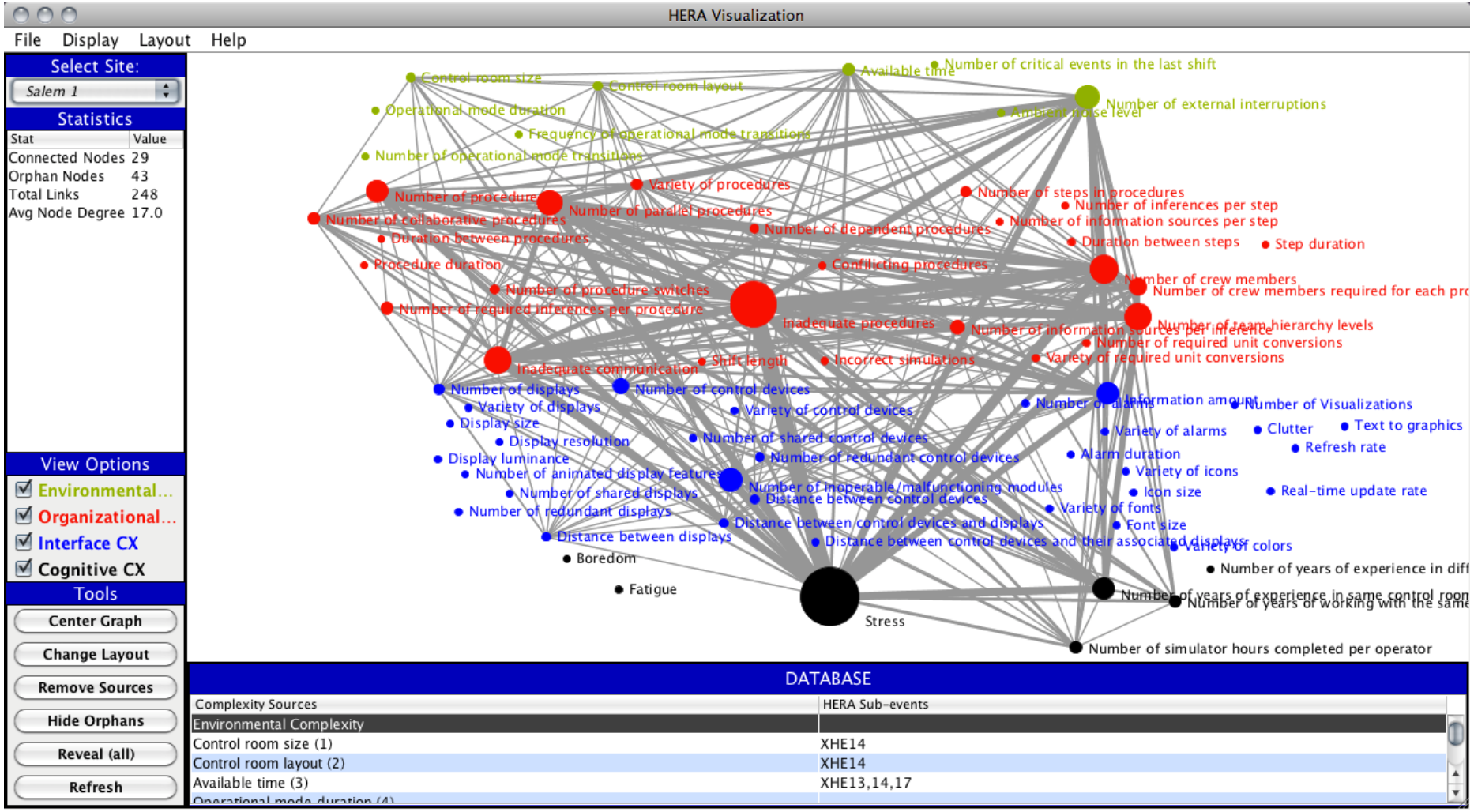
# of individual components and their connections as a direct measure of complexity (Edmonds, 1995)

"Deconstructionism" and "Dualism" (Dekker, 2003)

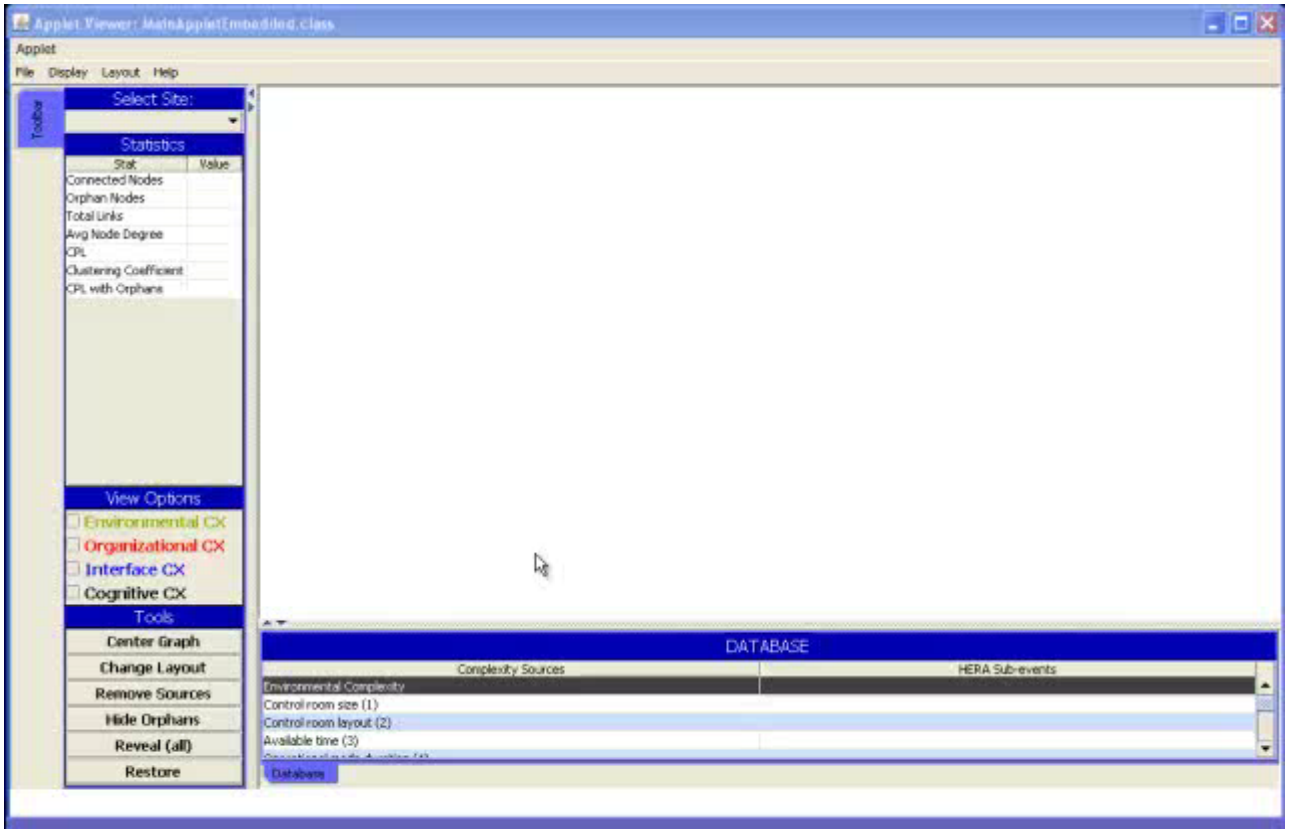
HSC complexity chain (Cummings & Tsonis, 2006)

Ensemble of CSNs

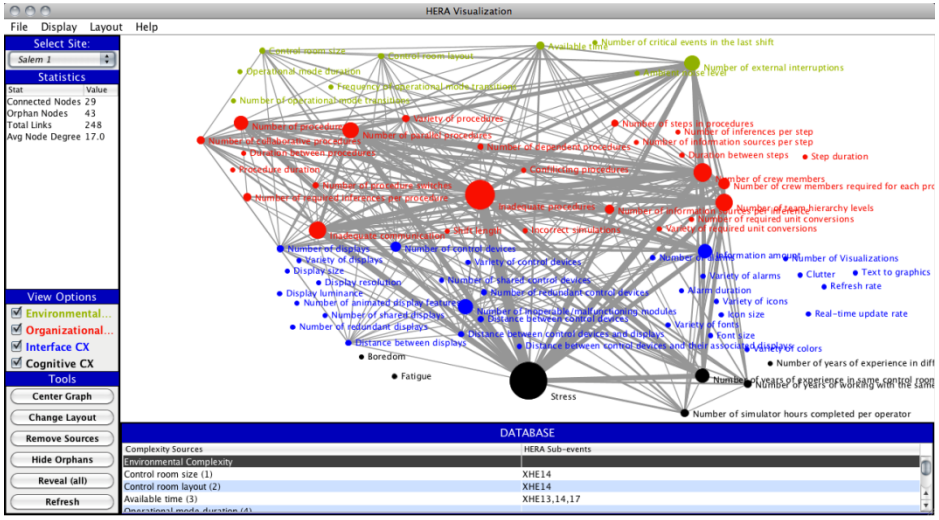
TOOLS: CXVIZ


HERA Visualization
File Display Layout Help
Select Site:
Salem 1
Statistics
Stat Value
Connected Nodes 29
Orphan Nodes 43
Total Links 248
Avg Node Degree 17.0
View Options
Environmental...
Organizational...
Interface CX
Cognitive CX
Tools
Center Graph
Change Layout
Remove Sources
Hide Orphans
Reveal (all)
Refresh
Control room size
Control room layout
Available time
Number of critical events in the last shift
Number of external interruptions
Operational mode duration
Ambient noise level
Frequency of operational mode transitions
Number of operational mode transitions
Number of procedures
Variety of procedures
Number of steps in procedures
Number of inferences per step
Number of parallel procedures
Number of collaborative procedures
Number of information sources per step
Number of dependent procedures
Duration between procedures
Duration between steps
Step duration
Procedure duration
Conflicting procedures
Number of crew members
Number of procedure switches
Number of crew members required for each pro
Number of required inferences per procedure
Inadequate procedures
Number of information sources per inference
Number of team hierarchy levels
Number of required unit conversions
Variety of required unit conversions
Inadequate communication
Shift length
Incorrect simulations
Number of displays
Number of control devices
Number of alarms
Information amount
Number of Visualizations
Variety of displays
Variety of control devices
Display size
Variety of alarms
Clutter
Text to graphics
Display resolution
Number of shared control devices
Refresh rate
Display luminance
Number of redundant control devices
Alarm duration
Number of animated display features
Variety of icons
Number of shared displays
Number of inoperable/malfunctioning modules
Icon size
Real-time update rate
Distance between control devices
Number of redundant displays
Variety of fonts
Distance between control devices and displays
Font size
Distance between displays
Distance between control devices and their associated displays
Variety of colors
Boredom
Number of years of experience in diff
Fatigue
Number of years of experience in same control room
Number of years of working with the same
Stress
Number of simulator hours completed per operator
DATABASE
Complexity Sources
HERA Sub-events
Environmental Complexity
Control room size (1)
XHE14
Control room layout (2)
XHE14
Available time (3)
XHE13,14,17

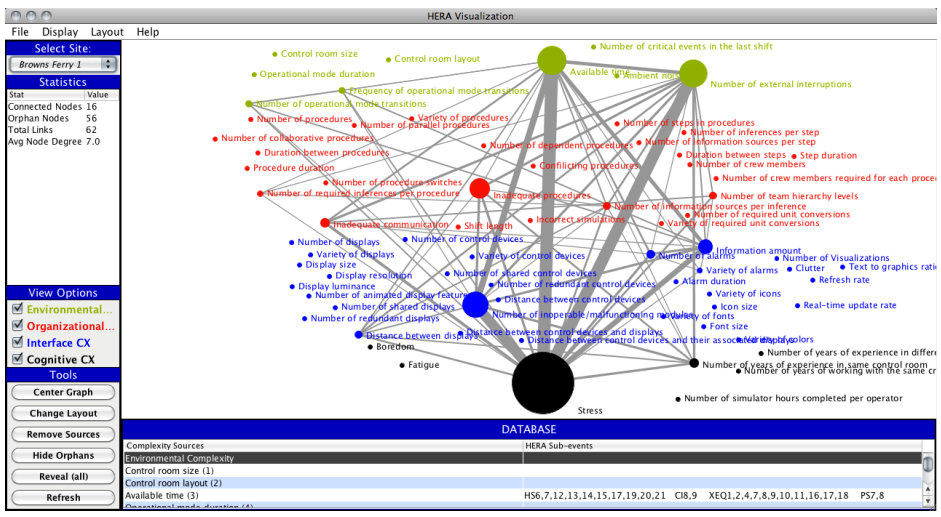
TOOLS: CXVIZ

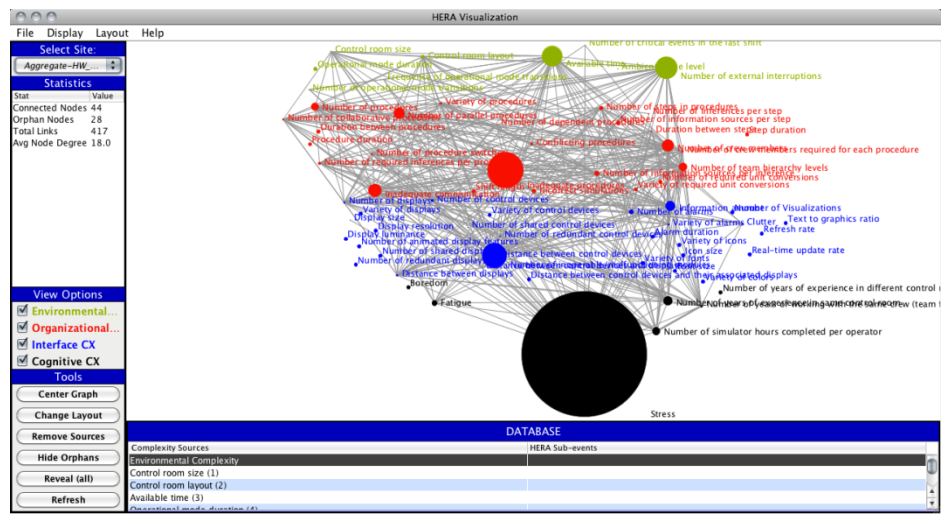

Applet Viewer: MainAppletEmbedded.class
Applet
File Display Layout Help
Toolbar
Select Site:
Statistics
Stat
Value
Connected Nodes
Orphan Nodes
Total Links
Avg Node Degree
CPL
Clustering Coefficient
CPL with Orphans
View Options
Environmental CX
Organizational CX
Interface CX
Cognitive CX
Tools
Center Graph
Change Layout
Remove Sources
Hide Orphans
Reveal (all)
Restore
DATABASE
Complexity Sources
HERA Sub-events
Environmental Complexity
Control room size (1)
Control room layout (2)
Available time (3)
Databases

TOOLS:CXVIZ

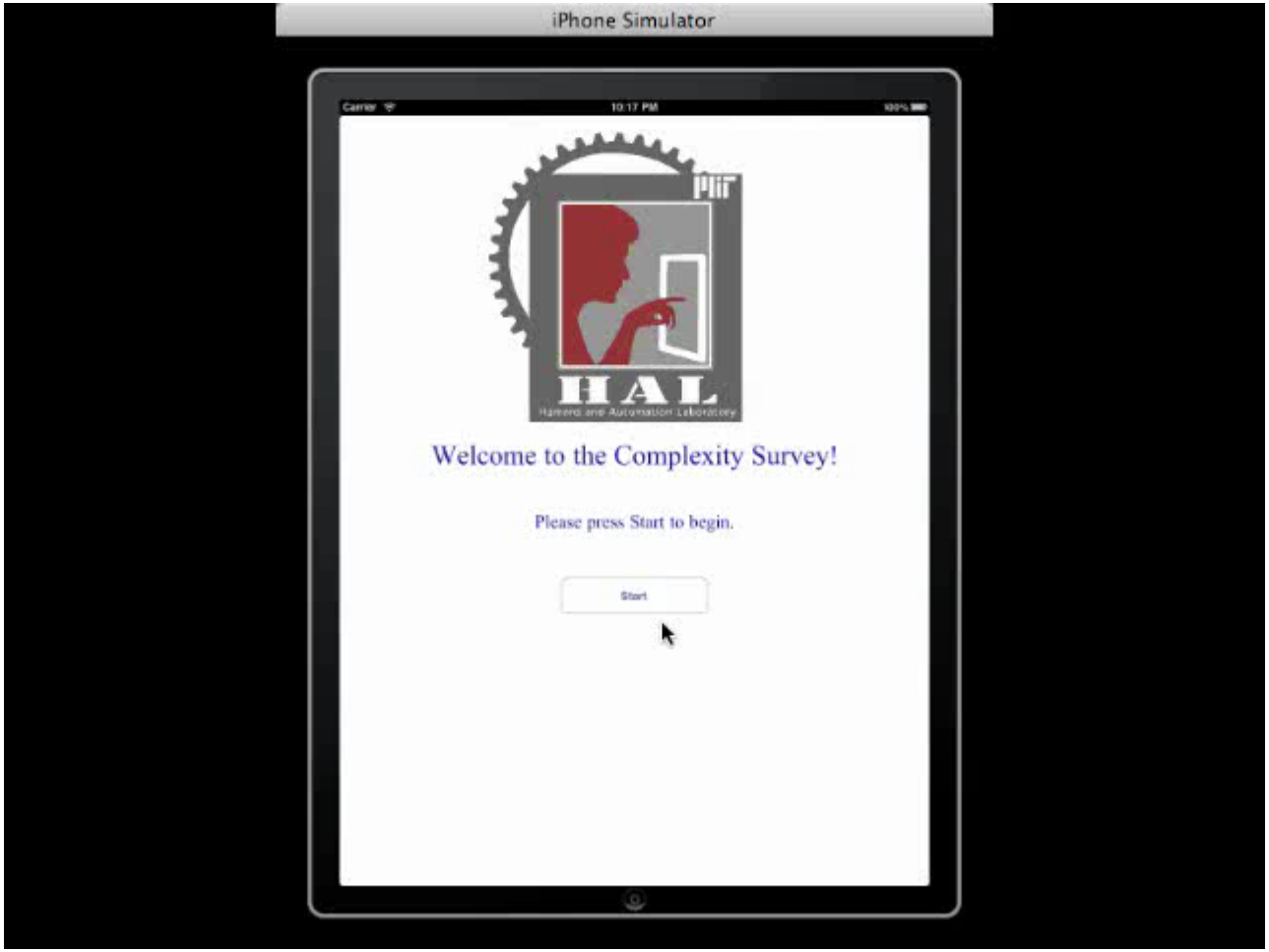


- Emergent Patterns
- Network Comparison
- Network Characteristics
- Network Dynamics
- Aggregate CSN





TOOLS: CXSURVEY



- To gather subjective complexity data
- 3 groups (operators, reviewers and designers)
- Portability
- Interactivity (drawing the interconnections)

CONCLUSION AND FUTURE WORK

- A methodology to:
  - Investigate complexity objectively and subjectively, and understanding the difference between two.
  - Investigate the difference in complexity views of stakeholders (operators, reviewers and designers)

- Develop tools to assess complexity (CXBundle)

- Develop design guidelines and prescriptions for acceptance of future designs

- Recommendations for complexity view alignment policies within stakeholder groups.

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For more information, please contact Farzan Sasangohar (farzans@mit.edu)

Or visit Humans and Automation Laboratory website: http://halab.mit.edu

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