Using STPA in the Design of a Nuclear Power Plant Control Room

A. Lucas STEPHANE

MS Business Intelligence

MS Experimental Psychology

Research Assistant

Florida Institute of Technology

April 19, 2012

MIT

Research Context (ongoing PhD) – digitalization of NPP MCR…

- *Sponsor*: AREVA R&D – Human Factors Department
- *Mission*: Force of Proposals
  - *Early exploration of relevant emergent technologies*

- *Vision*: sociotechnical Human Centric *Convergence*
  - Inter-domain (Aeronautics ➔ Nuclear, …)
  - Interdisciplinary (Psycho, Eco, Socio, Techno, Organizational)

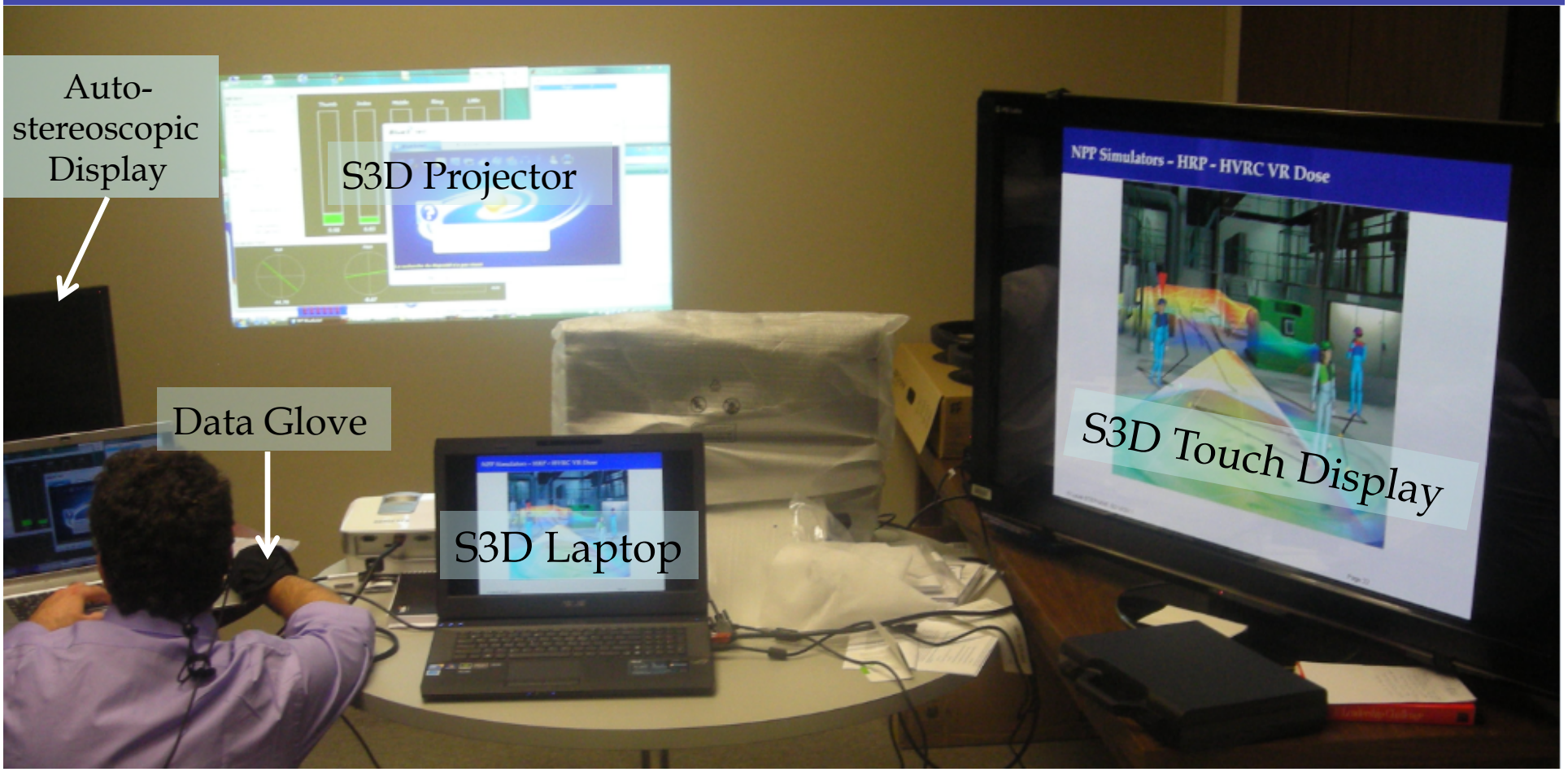
- *Research Focus*: Design & Evaluation of **Instruments & Controls (I&C)**
  - 3 main layers of intertwined requirements
    - Presentation
    - Content
    - Joint Activity (co-activity, interaction)

- *Target System*: **Safety Instruments & Controls System** (*SICS*)
- *Target location*: Nuclear Power Plant Main Control Room (*NPP MCR*)
- *Target population*: **Knowledge Workers**

Research Phase I

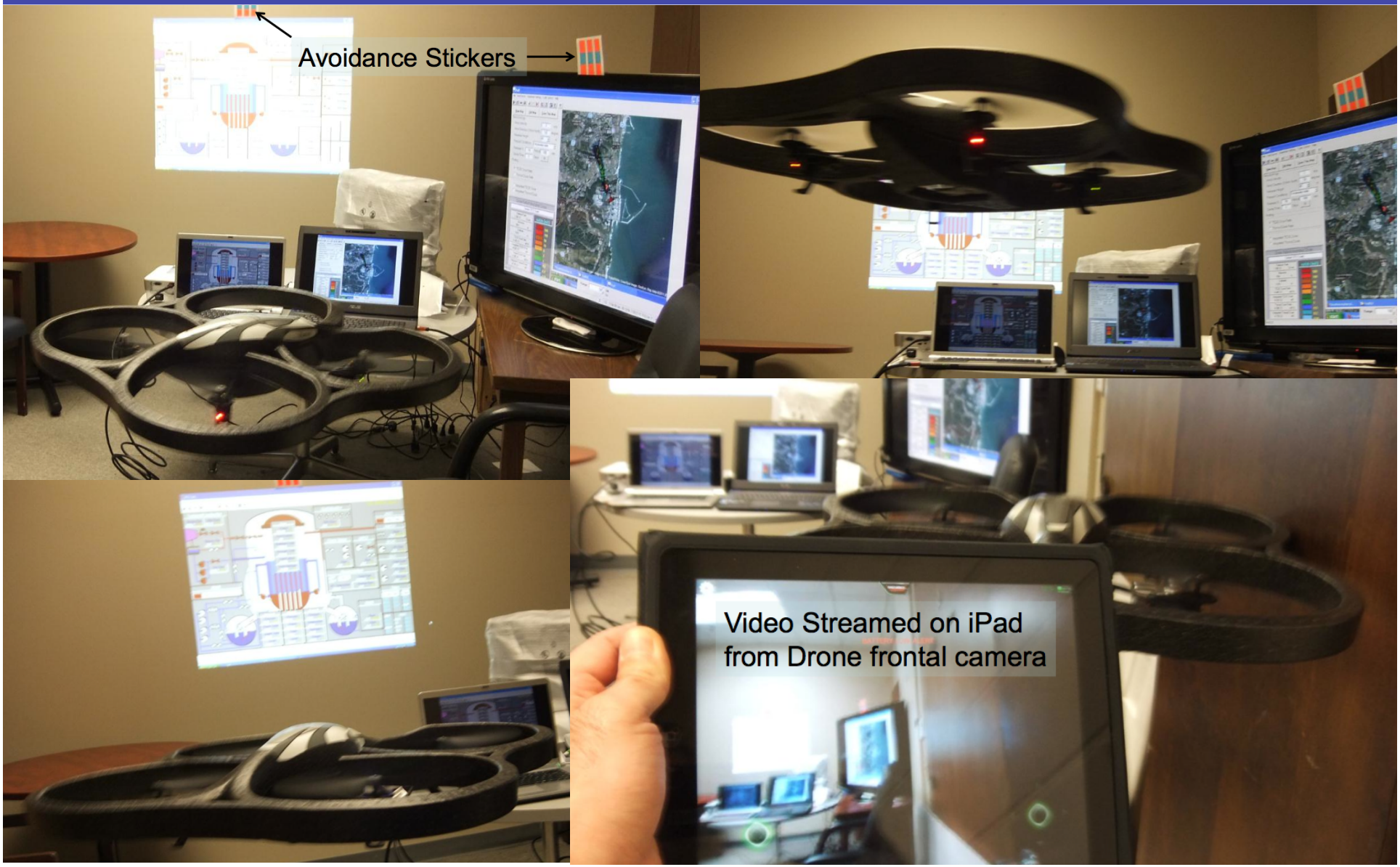
- *Phase I* - 2010: Exploration & Identification of
  - Technology
    - Stereoscopic 3D (S3D): compact & natural presentation/visualization
    - 3D Gaming Engines: *full* interactivity (vs. animation)
    - Touch surfaces (fixed & mobile): joint activity/interaction
    - personal Drone *in operations*: accessing dangerous locations
  - Content
    - plant subsystems (i.e. *partial* approach, *single unit*)
    - ***Incident*** scenarios
  - Sociotechnical modeling
    - Belief Desire Intention Multi-Agent Systems
      - ***External Viewpoint***: Roles, Responsibilities, Resources, Services
      - ***Internal Viewpoint***: Beliefs, Desires, Intentions
    - Service Oriented Architecture *Reference Architecture*
      - *techno mediation + management for Social Structures*
  - *Usability* Design & Evaluation methods
    - Situation Awareness (**rational** *external* aspects)
    - *Self* Awareness (motivation, emotions, loss-aversion, cognitive dissonance)
    - Workload
    - Eye Tracking

Phase I: Lab Configuration…

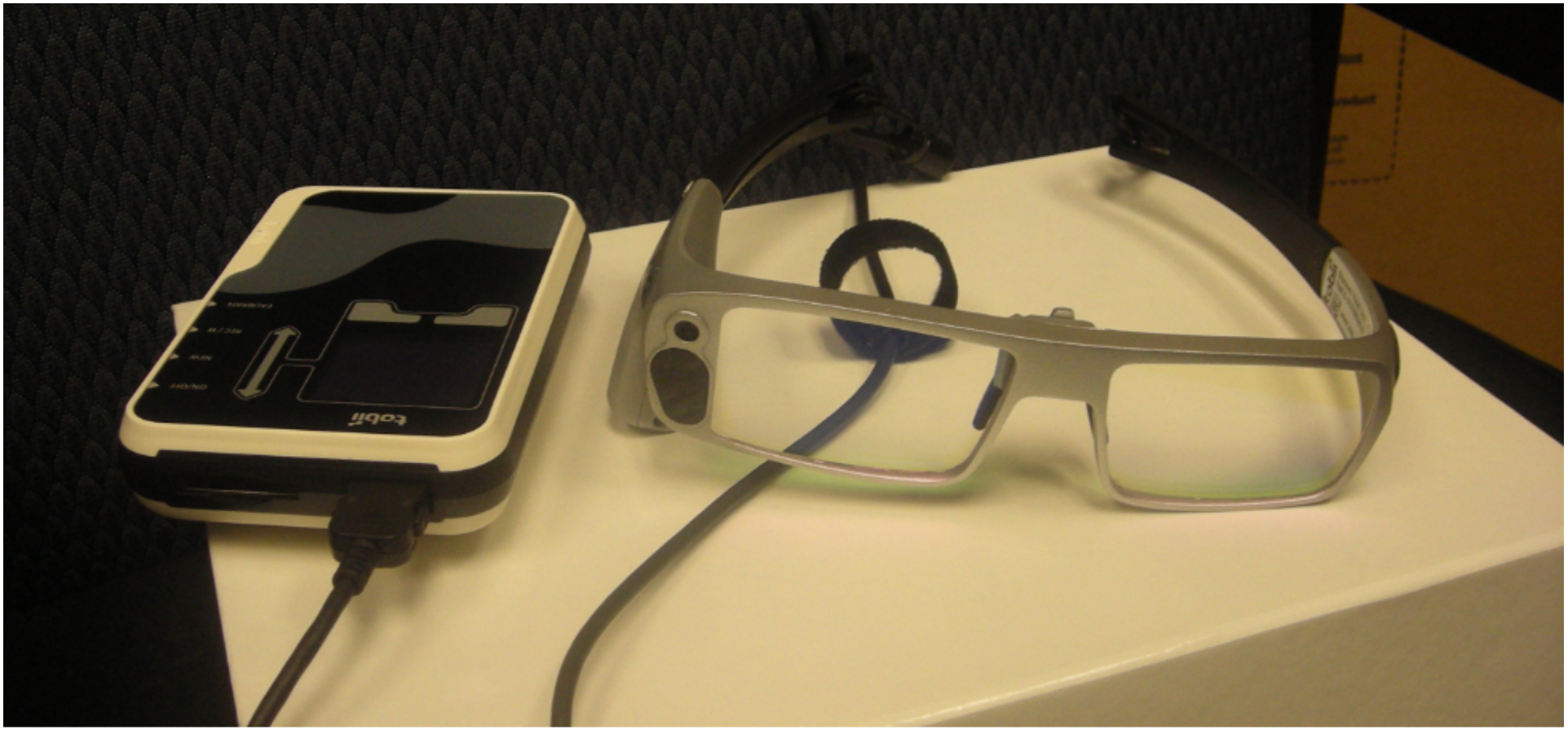


Phase I: Lab Configuration…Touch surfaces: Tablet (*Remote Desktop*) & Touch Screen

Phase I: Lab Configuration…Personal Drone – Fly using tablet



Phase I: Lab Configuration…Eye Tracking



Research Phase II

- *Phase II* - 2011: Fukushima and after…

  ⇒ Reinforcing **Safety in Design & Evaluation**
  - **Requirements Management in terms of Safety Criteria for Design & Evaluation** (beyond Usability)
    - Integration of Safety & Usability methods & criteria…
  - **STAMP, STPA & SpecTRM proposed during Fall 2011**

  ⇒ **Content for uncertain/unpredicted/unpredictable situations**
  - ***Uncertainty*** approaches in design (KOMPASS)
  - ***Adaptive Case Management***: shift from *process improvement* (analytic stage) toward *process execution* (operations stage)

  ⇒ **Accident** scenarios & processes
  - Fukushima accident understanding…
  - Considering **multiunit** events & crisis management (Units 1 to 4)
    - **Complexity** & uncertainty in understanding (i.e. NUREG-1935)
      ⇒ Complexity in design – intellectual unmanageability…
  - *Global* approach

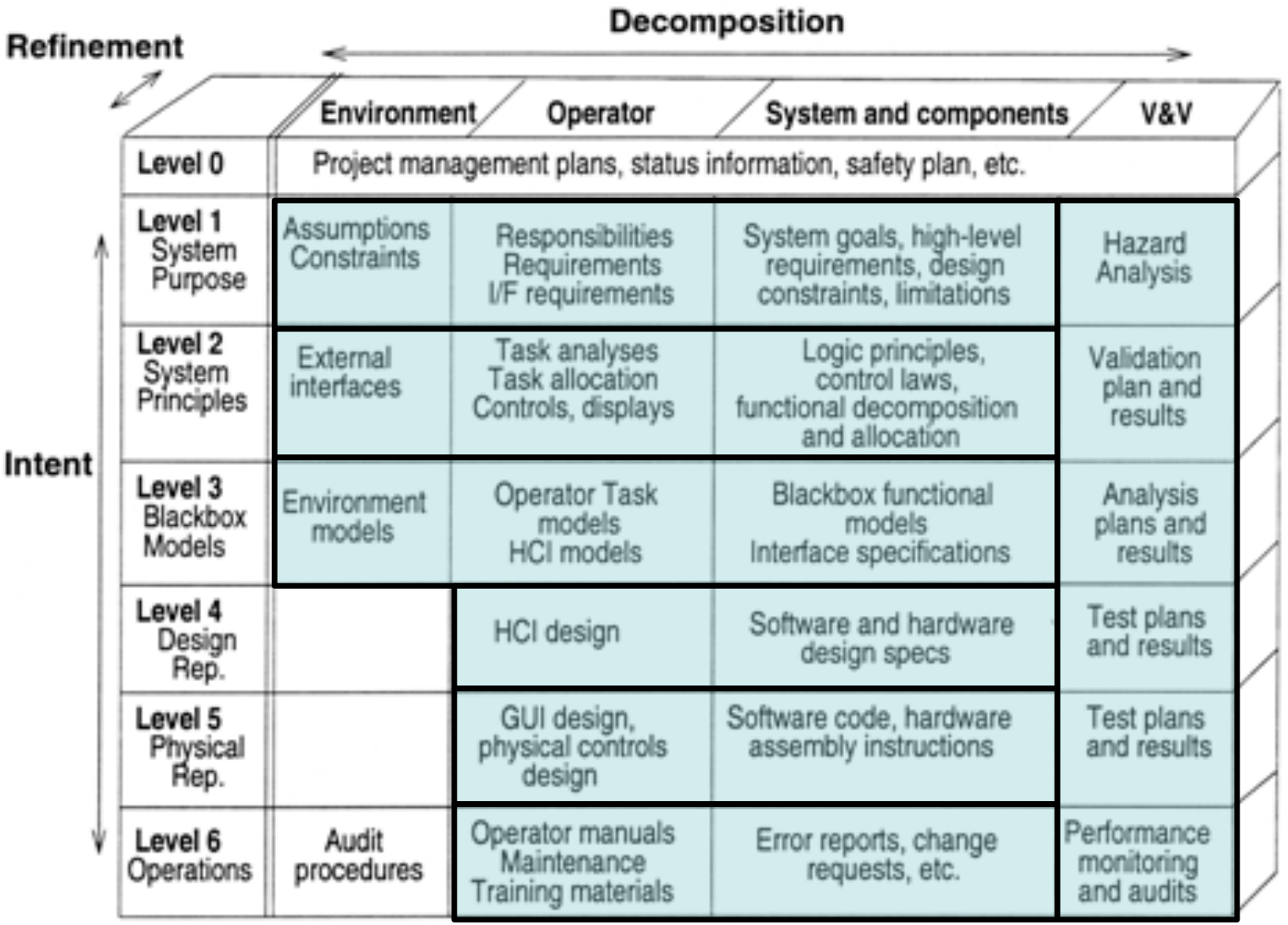
Phase II: Integration toward Human Centric Convergence

DESIGN STAGE	Safety Methods	BDI MAS	SOA RA	BPMN	Uncertainty
Main Outputs & Span	- Analysis - Drive Specifications - Drive Implementation	- *Sociotechnical Cognitive Modeling* - *Implementation*	- *Reference Architecture* - Drives Specifications - Drives Implementation	- *Standard Notation* - *Modeling* - *Implementation*	- Sociotechnical Criteria - *Recommendations*
Artifact(s)	- Interdependent *Intent* Specifications - Human-Computer *Interaction* - *Constraints*	- *Interaction Service* Providers - Communication - External & Internal viewpoints	- *Interaction Service* Providers - *Constraints* - *Quality of Service*	- *Interaction Service* Providers	- Automation types - *Limits of Control*
User(s)	- Responsibilities - Requirements - Operator Task models - HCI models	- Roles, Responsibilities, Resources, Services - *External & Internal* viewpoints	- part of the ***Social Structure*** - *Interaction* driven by *Intent* - *External* viewpoint	- Information Providers & Consumers	- Expertise - *Motivation*
Task(s)	- *Safety Margins/Constraints* - Analysis - Allocation - *Dysfunctional Interactions*	- Agent plans (partial or complete) - Parallel execution	*Achieve Awareness* in: - *Orchestration* - *Collaboration* - *Choreography*	- *Orchestration* - *Collaboration* - *Choreography* - Parallel execution	- *Process transparency* - *Dynamic Coupling in Process Control*
Organization(s)	- *External Interfaces* - *Environment Models* - Audit - *Resilience* - *Adaptability*	- no specific support (i.e. any)	- *Governance* - *Regulations* - *Contracts* - *Security Model* - *Flexibility* - *Agility* - *Adaptability*	- Inherit SOA reference features	- Rigid vs. Flexible - *Adaptability*
Situation(s)	- *Incidents & Accidents* explicitly considered - *Hazard Analysis*	- no specific support (i.e. any)	- Case Analysis (*functional & non-functional*)	- *Incidents & Accidents* explicitly considered through *Event Escalation*	- no specific support (i.e. any)

Phase II: How: Non-Linear Safety methods - retrospective & prospective

- Fukushima Dai-Ichi **Multiunit** Accident Analysis using:
  - primary sources (TEPCO, NISA)
  - secondary sources: (IAEA, NUREG, AREVA and other reports)
  - STAMP: accident understanding…
  - STPA & SpecTRM: Design & Evaluation
- **STAMP output:** identifying main directions for the current design
  - holistic vertical (organizational layers) & horizontal (multiunit) analysis
- **STPA output:** providing **Safety Margins criteria for**
  - *Designing* the proposed I&C (visualization & controls; processes; decision-making under uncertainty)
  - *Evaluating* the proposed I&C
- **SpecTRM outputs**
  - Create Intent Specifications
  - Perform STPA
  - Verify & Validate Models through *Simulation* & *Experimentation*

Phase II: STPA - SpecTRM



DR record from the SpecTRM user guide. © SafeWare 2011

Phase II: WHAT

WHAT is to be achieved:

- Design and Evaluate **S3D representations of I&C for the Safety Instruments & Controls System (*SICS*)** that aim to **improve safety support for decision-making and consequent operations** (i.e. crisis management) in an accidental scenario
- Such S3D representations span both situated **Visual aspects** as well as **Collaborative aspects** (joint activity, interaction)
- **Direct Interaction** supported by **touch features** is accorded the main emphasis
  - **Controls are embedded in the visual scene**

Phase II: WHAT

WHAT S3D content:

- **Two main classes of I&C**
  1. **Internal I&C** related to the NPP: temperature, pressure, sociotechnical system states, **main plant organs** (i.e. reactor, Spent Fuel Pool, Diesel Generators) and their **trends**
  2. **External I&C** related to the **environment**: possible impacts on the environment
- **Two classes of processes** (including *analytic* aspects related to states and dynamics) in *normal* & *abnormal* conditions
  1. **Predefined processes** (if/when available)
  2. **Adaptive processes** in case no predefined processes are available (errors, exceptions, escalation)

Phase II: WHY

WHY such S3D representations & content:

- In current visual environments overloaded with information, **S3D representations** offer an efficient alternative for **tackling information density under time pressure**

- **Deep content** related to *Decision Making & Action*
  - **Games against 'Nature'**
    - **Influence Diagrams & *Dynamic* Bayesian Networks**

  and
  - **Imperfect Information Games**
    - **plans of action** (*BPMN process representations*)

- **S3D mapping of Context Space & Resources Space** for enhancing *understanding & awareness*

Phase II: WHY

WHY such a context:

- The **accidental context enables to demonstrate the usefulness of S3D representations & content, supported by relevant devices**

⇒ **Design a minimal autonomous I&C for Vertical & Horizontal communication and collaboration**

  - **networked handheld devices** (i.e. **tablets**): **loss of electrical power** (i.e. *Station Black Out*)
  - **personal drones** in operations: **surveillance & monitoring** of equipment **in inaccessible locations** (i.e. due to high radioactivity levels)

- *It is assumed that at least in one location, one S3D display can function…*

Phase II: How: *Core of the study*

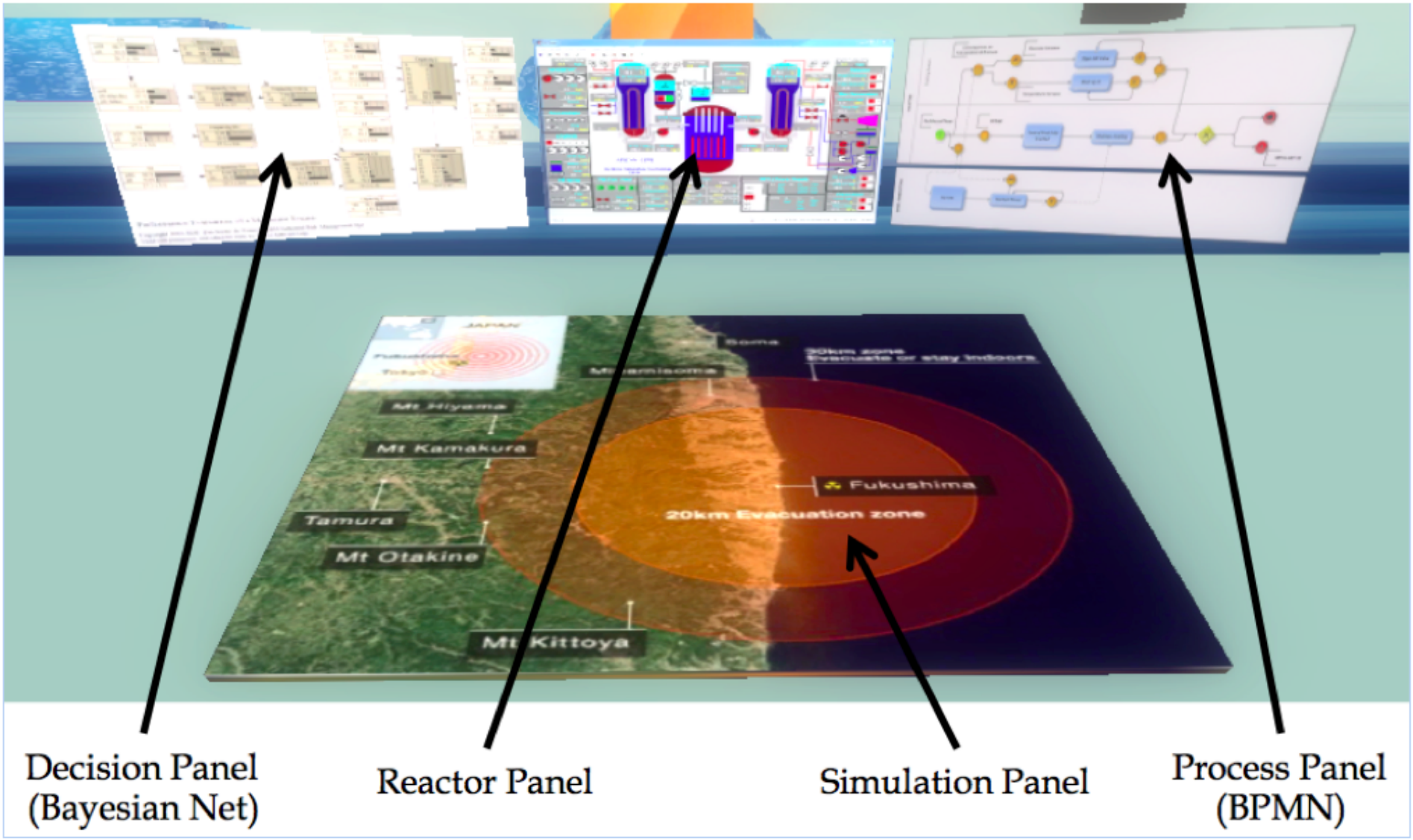
***Hard* Decision-Making in uncertain / unpredicted / unpredictable situations:**

- Based on the ***prescriptive decision analysis approach*** **(*Goal-driven*)**
  - **Influence Diagrams & *Dynamic* Bayesian Networks : prior (subjective) probabilities (human collaboration)**
  - **Preferences**
  - **Risk analysis**
    - ***Conflicting Objectives***
  - **Trade-offs / Satisficing / Sacrificing**
  - **... Adaptive Case Management**

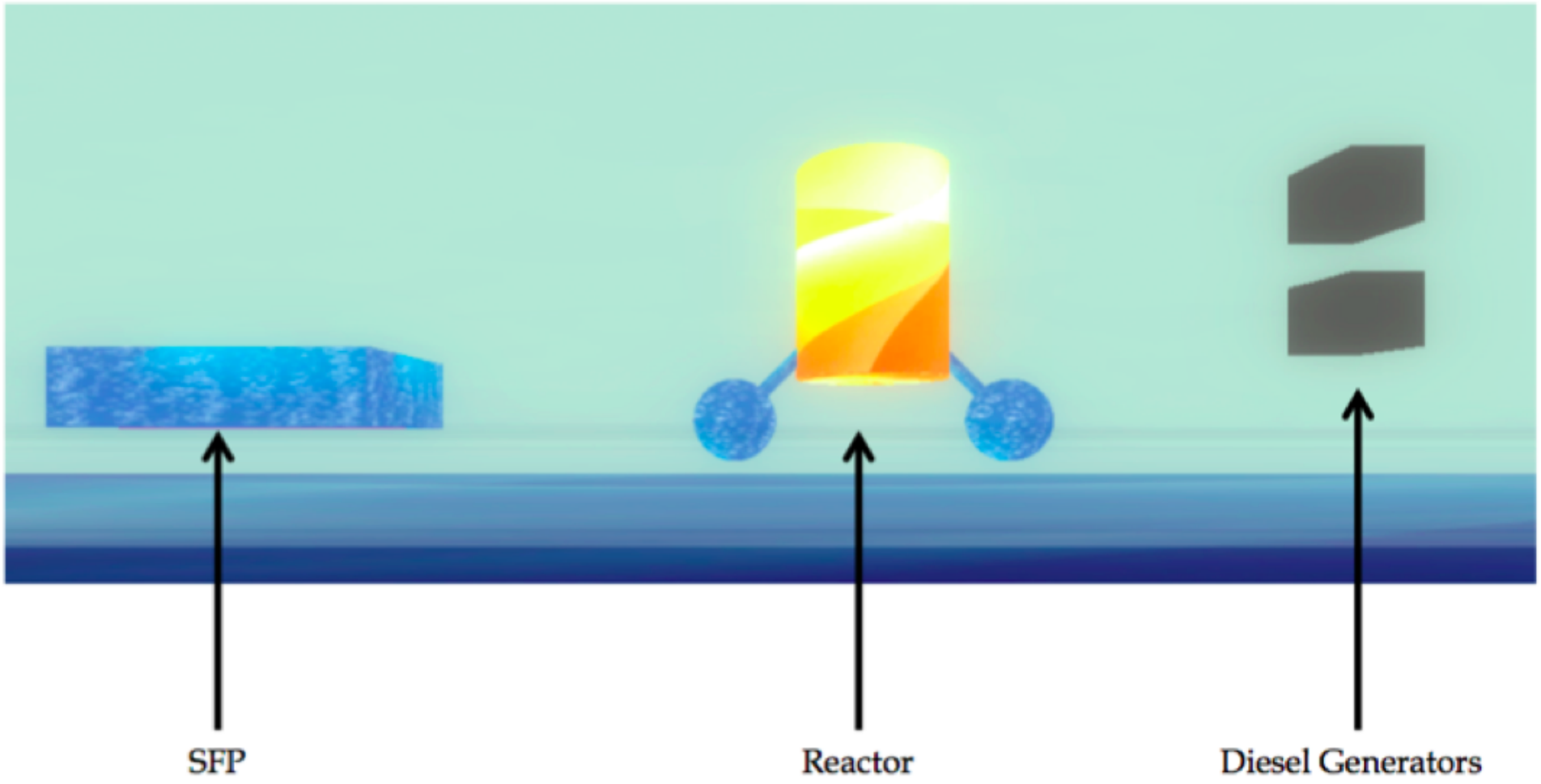
- **Completed with *consequent adaptive plans of action* (*Event-driven*)**
  - **Adaptive BPMN**
  - **Coopetition**

- ***Similar approaches: Integrated Risk Picture (SESAR); AgenaRisk***
  - ***Difference: in these approaches, probabilities are proposed ex-ante…***

Phase II: How much: *Specifications & Implementation*



Phase II: How much: *Specifications & Implementation*



…Multiunit in a near future…

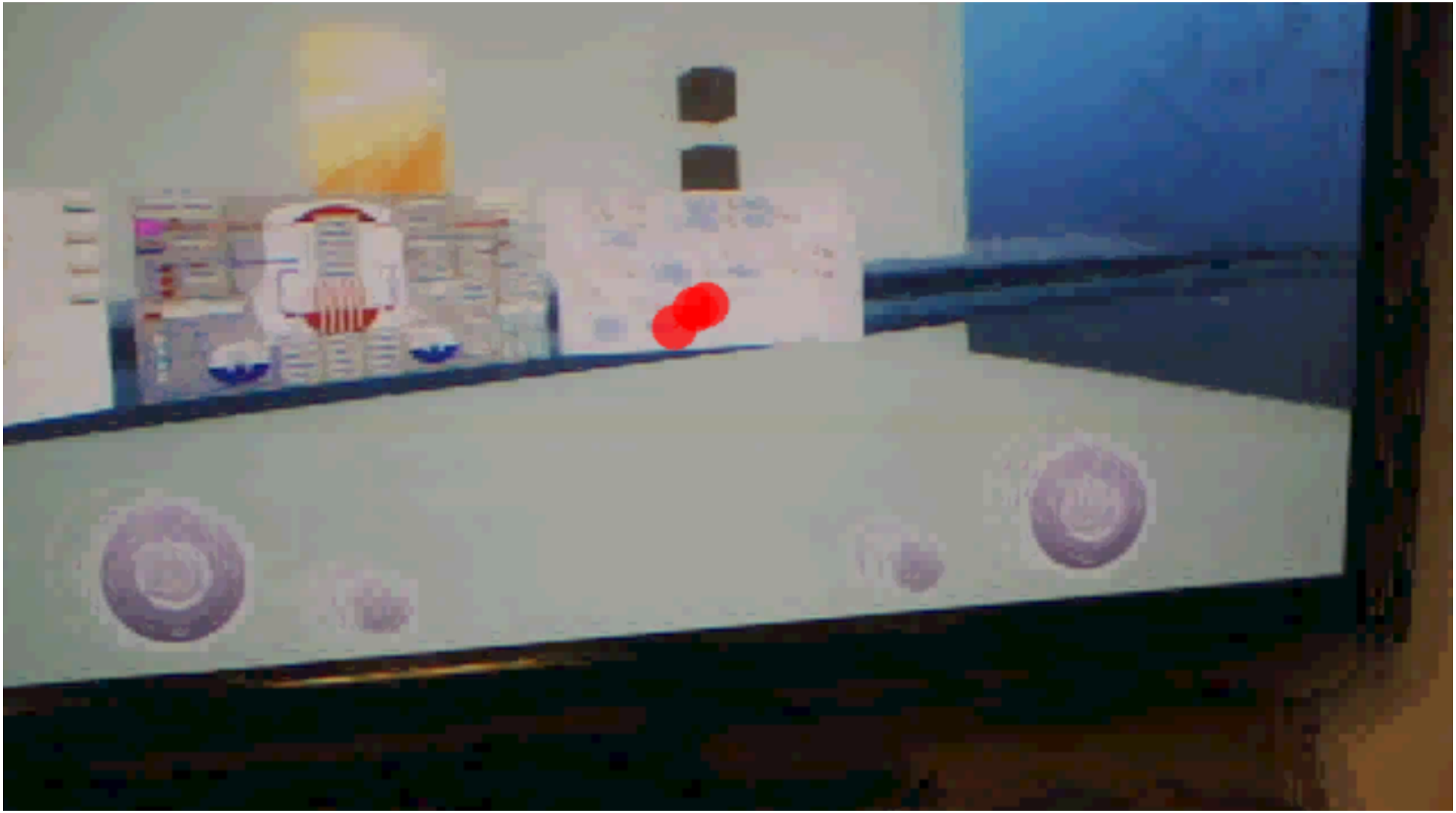
Phase II: How much: *Experiment Design*

Scenarios

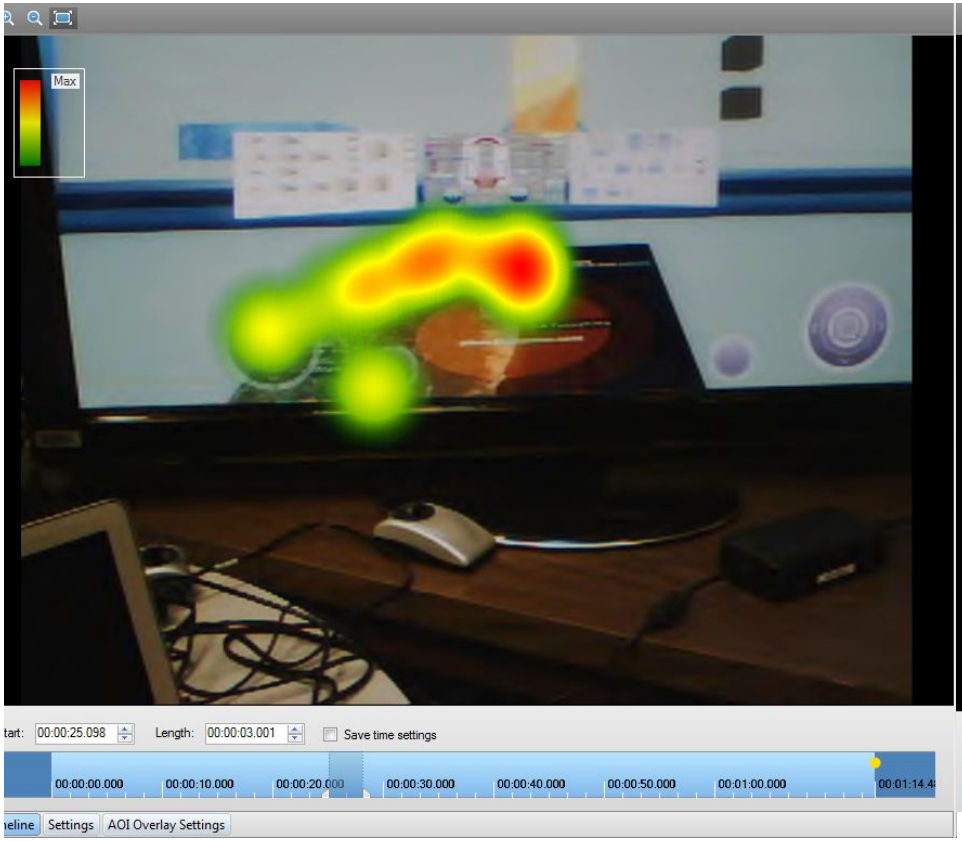
- Based on **Life-Critical Role-Playing Game**
- Implementing **decisions & consequent actions in terms of multiple choices of explicitly valuated spatiotemporal losses / gains (payoffs)** - human, technical systems, environmental, financial - **under pressure & incentives**
- Timeline
- User profiles (personae)
  - Scientific (mathematics; physics,…)
  - Engineering
  - Business, political…

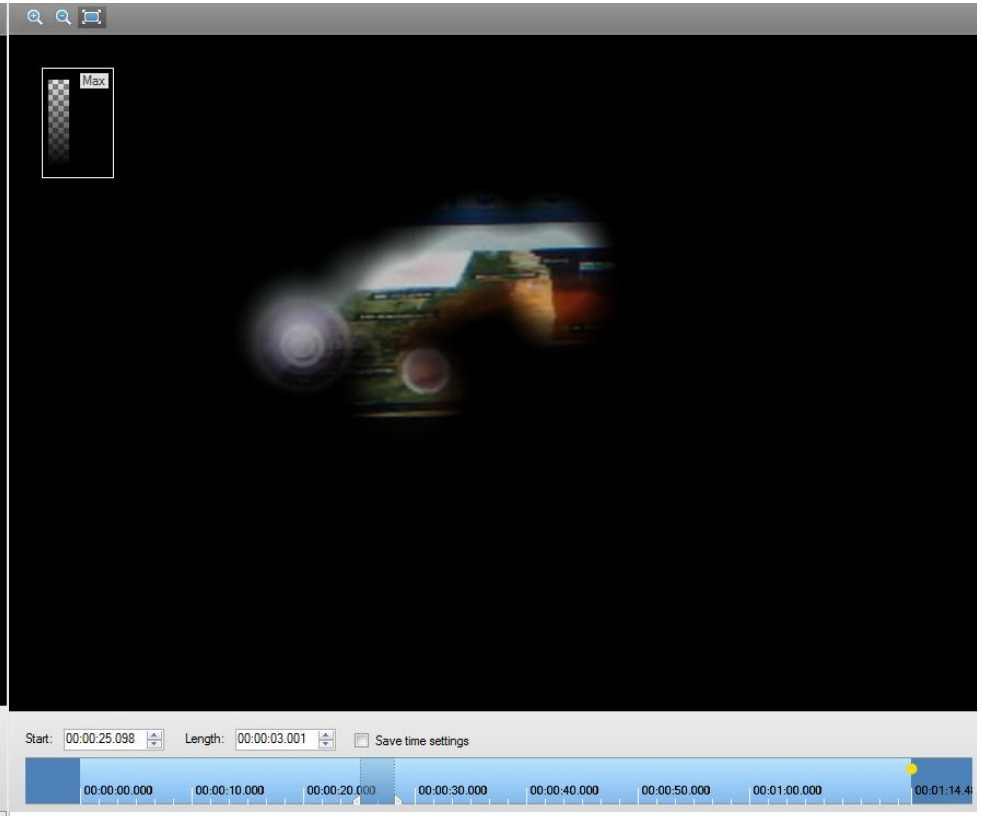
Ongoing Tests & Refinements…

Ongoing Tests - Eye Tracking…

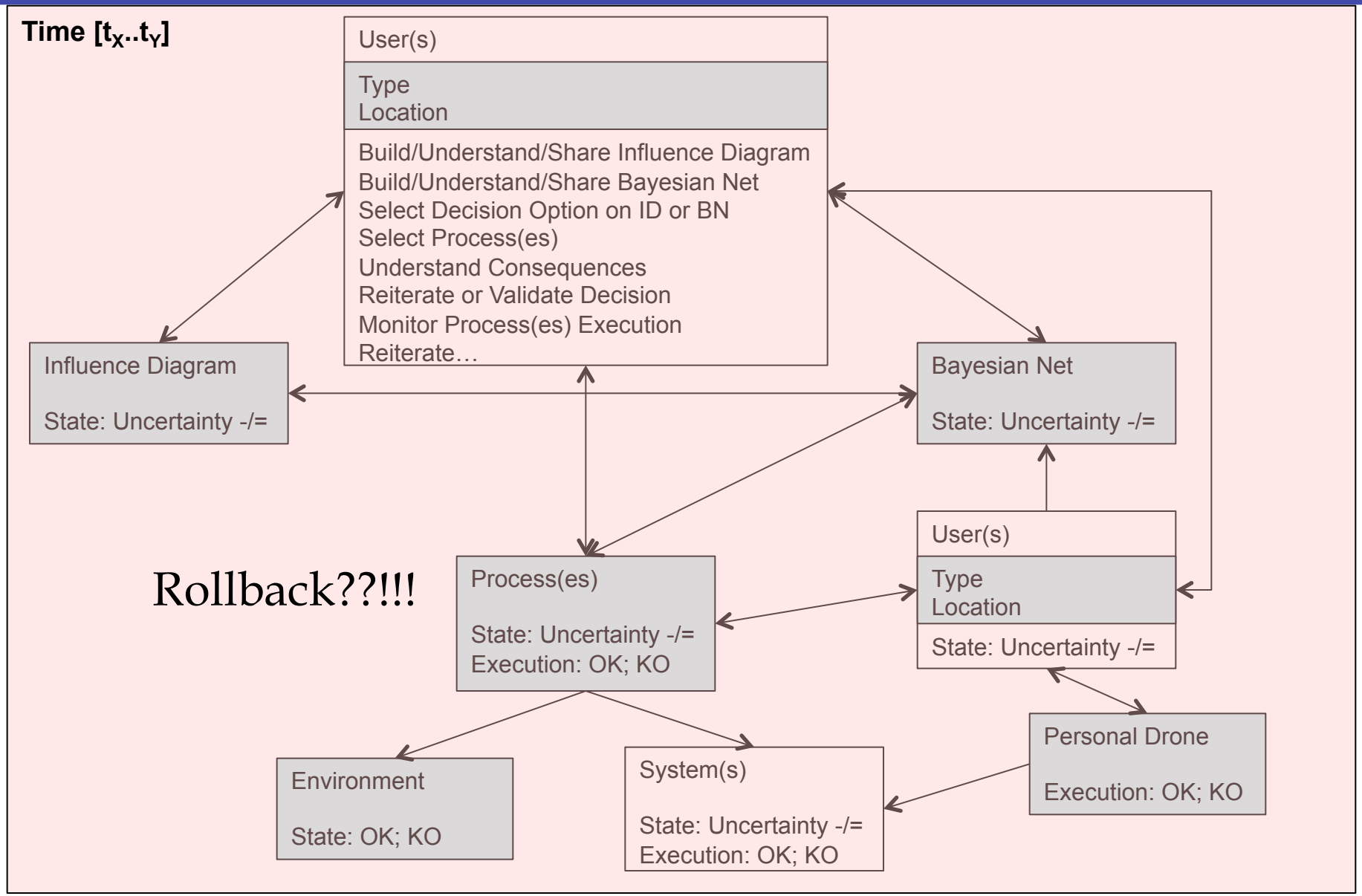


Ongoing Tests - Eye Tracking…

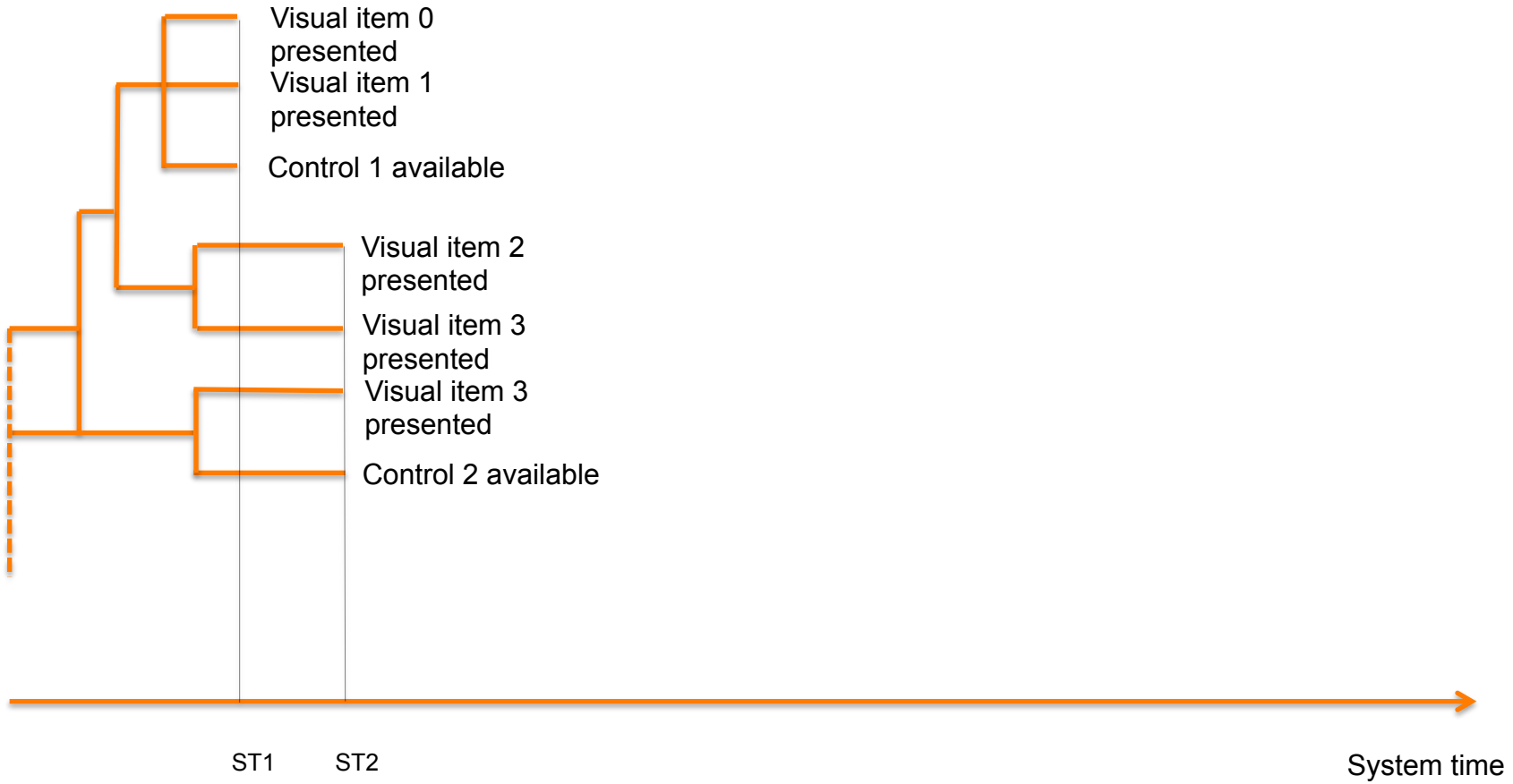




Perspectives: STPA for sociotechnical spatiotemporal patterns

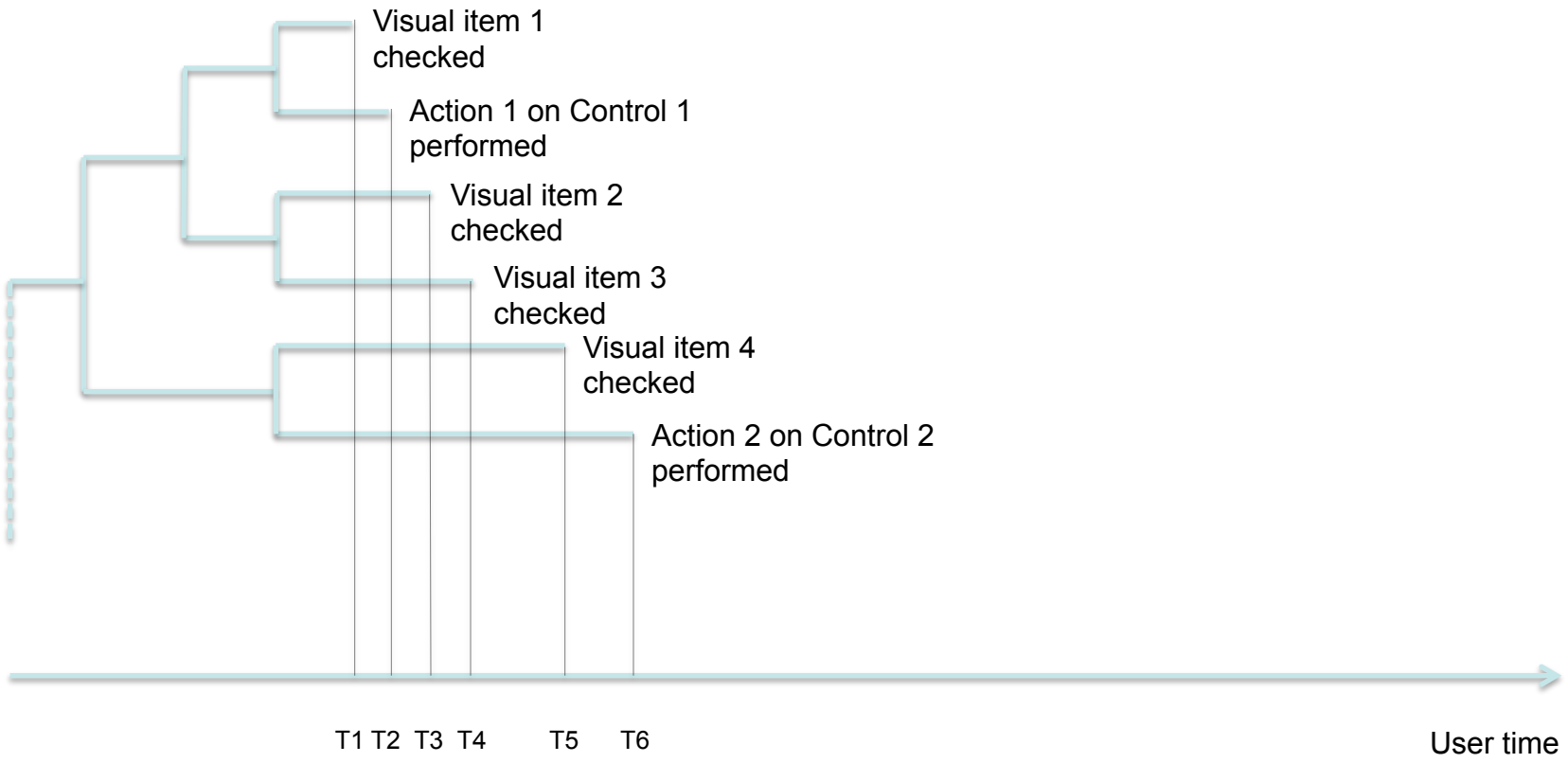


Perspectives: STPA for sociotechnical spatiotemporal patterns



System Dynamic Pattern (*ex ante* – i.e. Design)

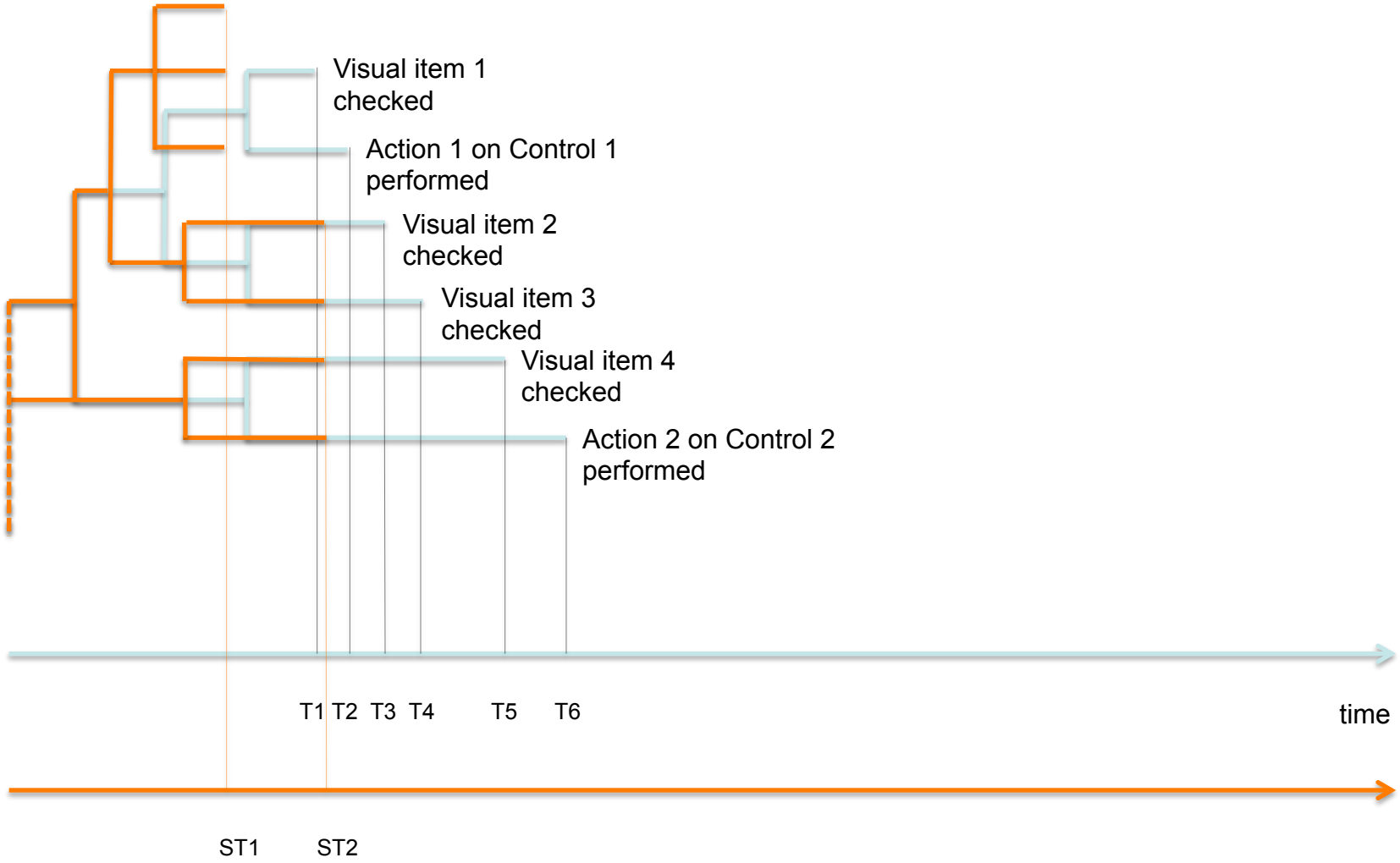
Perspectives: STPA for sociotechnical spatiotemporal patterns



User Behavior Pattern (*ex post*)

S.M. Magnusson: T-patterns

Perspectives: STPA for sociotechnical spatiotemporal patterns



Sociotechnical Pattern (*ex post*)

Conclusion

- Focus on dynamic uncertainty
- Tackle accidental contexts (past and possible) and integrate *user feedback* in design

- Safety on top of Usability
- Integration of Safety and Usability methods for Design & Evaluation

- Multidirectional training: users – designers – evaluators…

Acknowledgments

- Dr. Nancy Leveson, MIT
- Dr. Margaret Stringfellow, MIT

- Dr. Guy Boy, FIT
- Dr. Semen Köksal, FIT
- Dr. Jeffrey Bradshaw, IHMC
- Dr. Andrew Duchowski, Clemson University
- Dr. Marco Carvalho, FIT

- HF Expert Ludovic Loine, AREVA

- Dr. Sherry Borener, FAA
- Dr. Thierry Bellet, IFSTTAR
- Dr. Gudela Grote, ETH

Discussion…

Questions & Feedback are welcome

Thanks ☺

Lucas STEPHANE
astephane2010@my.fit.edu
(+1)321-549-0207