# State Event Models for the Formal Analysis of Human-Machine Interactions

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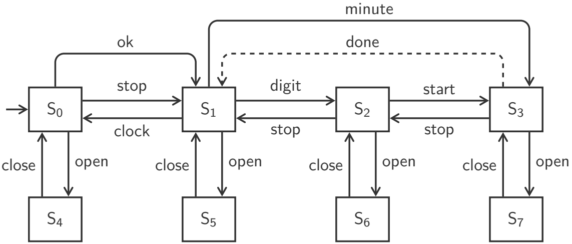
# Introduction

- Automated formal analysis techniques for HMI systems
- Detection of potential automation surprises
- Conformance relation between actual system and mental model according to which it is operated

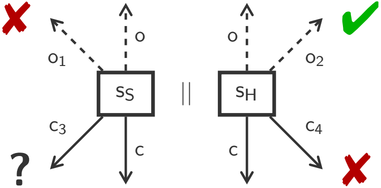
# Formal Modelling

- HMI-LTS extends LTS with inputs and outputs:
  - Commands executed by the user
  - Observations executed by the system and observed by the user
  - Internal actions invisible to the user



# Interaction Model

- **Interaction:**
  - Represented with the synchronous parallel composition



- **Bad situations:**
  - A command missing on the system model ($c_4$)
  - An observation missing on the mental model ($o_1$)

# Full-control property

- Full-control property captures safe interaction
- During the interaction between a user and a system:
  - The user must know exactly the possible commands...
  - ...and at least all the possible observations

$\mathcal{H} \,\mathrm{fc}\, \mathcal{S}$ if and only if :

$\forall \sigma \in \mathcal{L}^*$ such that $s_S \in (s_{0_S}\ \textbf{after}\ \sigma)$ and $s_H \in (s_{0_H}\ \textbf{after}\ \sigma)$ :

$$A^c(s_S) = A^c(s_H) \quad \text{and} \quad A^o(s_S) \subseteq A^o(s_H)$$

# Generation Problem

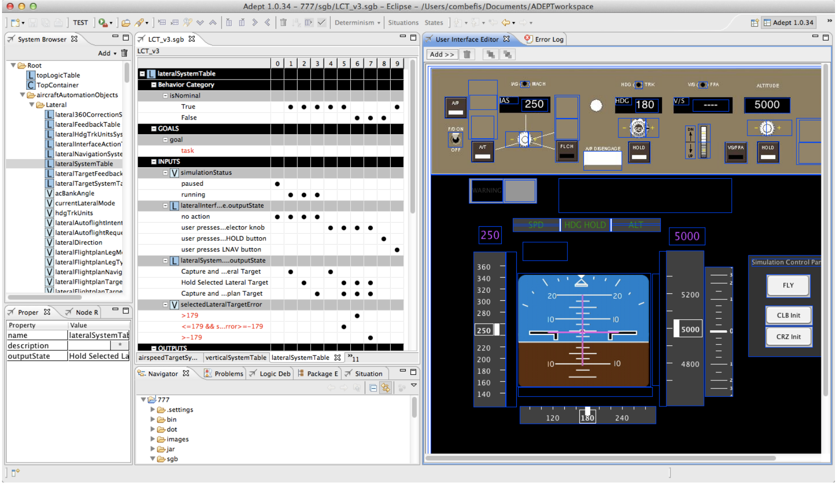
- **Goal:** Given the model of a system, automatically generate a minimal full-control conceptual model

- **Motivation:**
  - Extract the minimal behaviour of the system, so that it can be controlled without surprise
  - Help to build artifacts: manuals, procedures, trainings, . . .
  - If such abstraction does not exist, provide feedback to help redesigning the system

# ADEPT toolset

- Automatic Design and Evaluation Prototyping Toolset
- Java-based tool
- Support designers in early prototyping phases of automation interfaces

# Autopilot ADEPT model I



- Root
  - topLogicTable
  - TopContainer
  - aircraftAutomationObjects
    - Lateral
      - lateral360CorrectionS
      - lateralFeedbackTable
      - lateralHdgTrkUnitsSys
      - lateralInterfaceAction
      - lateralNavigationSyste
      - lateralSystemTable
      - lateralTargetFeedback
      - lateralTargetSystemTa
      - acBankAngle
      - currentLateralMode
      - hdgTrkUnits
      - lateralAutoflightIntent
      - lateralAutoflightReque
      - lateralDirection
      - lateralFlightplanLegM
      - lateralFlightplanLegTy
      - lateralFlightplanNavig
      - lateralFlightplanTarge
      - lateralFlightplanTarge

| Property | Value |
|---|---|
| name | lateralSystemTab |
| description | * |
| outputState | Hold Selected La |

LCT_v3

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| lateralSystemTable | | | | | | | | | | |
| Behavior Category | | | | | | | | | | |
| isNominal | | | | | | | | | | |
| True | | ● | ● | ● | ● | ● | | | | ● |
| False | | | | | | | ● | ● | ● | |
| GOALS | | | | | | | | | | |
| goal | | | | | | | | | | |
| task | | | | | | | | | | |
| INPUTS | | | | | | | | | | |
| simulationStatus | | | | | | | | | | |
| paused | ● | | | | | | | | | |
| running | | ● | ● | ● | | | | | | |
| lateralInterf...e.outputState | | | | | | | | | | |
| no action | ● | ● | ● | ● | | | | | | |
| user presses...elector knob | | | | | ● | ● | ● | ● | | |
| user presses...HOLD button | | | | | | | | | ● | |
| user presses LNAV button | | | | | | | | | | ● |
| lateralSystem....outputState | | | | | | | | | | |
| Capture and ...eral Target | | ● | | | ● | | | | | |
| Hold Selected Lateral Target | | | ● | | | ● | ● | ● | | |
| Capture and ...plan Target | | | | ● | | ● | ● | ● | | |
| selectedLateralTargetError | | | | | | | | | | |
| >179 | | | | | | | ● | | | |
| <=179 && s...rror>=-179 | | | | | | ● | | | | |
| >-179 | | | | | | | | ● | | |
| OUTPUTS | | | | | | | | | | |

airspeedTargetSy... verticalSystemTable lateralSystemTable »11

- 777
  - .settings
  - bin
  - dot
  - images
  - jar
  - sgb

# Autopilot ADEPT model II

| | 0 | 1 |
|---|---|---|
| **L airspeedFeedbackTable** | | |
| **INPUTS** | | |
| L airspeedSystemTable.outputState | | |
| Maintain Airspeed Target | ● | |
| Capture Airspeed Target | ● | |
| Hold Current Airspeed | ● | |
| Protect Airspeed Target | | ● |
| **OUTPUTS** | | |
| C pfdAirspeedTape.currentValue | | |
| V indicatedAirspeed | ● | ● |
| C cautionLabel.background | | |
| 255, 204, 0 | | ● |
| C autothrottleModeFailureBar.opaque | | |
| False | ● | |
| True | | |
| C pitchModeFailureBar.opaque | | |
| False | ● | |
| True | | |
| C pfdAirspeedTape.preSelectedTarget | | |
| V selectedSpeedTarget | | ● |
| C pfdAirspeedTape.selectedTarget | | |
| V selectedSpeedTarget | | ● |

# State Event Models

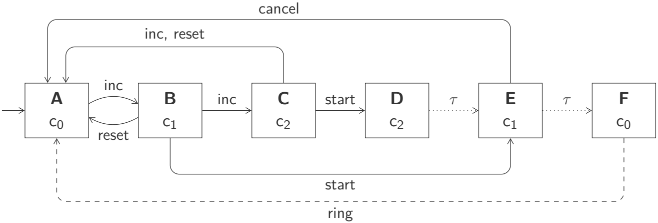
- ADEPT models combine state with transition information
- A state is made of $n$ variables $x_i$ ranging over domains $D_i$
- Only some state-variable are visible

$$\begin{tikzcd}
\boxed{\langle x_1 = v_1, \ldots, x_n = v_n \rangle} \arrow[r] & \boxed{\langle x_1 = v'_1, \ldots, x_n = v'_n \rangle}
\end{tikzcd}$$

**HMI-LTS are enriched with state-values**

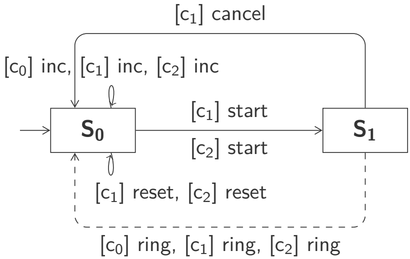
# HMI State-Valued System Model

- Each state $s$ is associated with a state-value $\mathcal{O}(s)$
- Two kinds of observations are possible in a system



# HMI State-Valued Mental Model

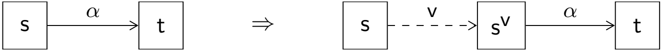
- Transition are guarded with a state-value
- A transition will be executed if the guard is satisfied in the current state of the system



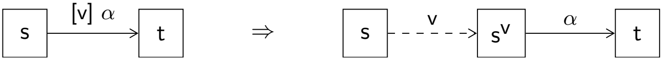
[$c_1$] cancel
[$c_0$] inc, [$c_1$] inc, [$c_2$] inc
[$c_1$] start
$S_0$
$S_1$
[$c_2$] start
[$c_1$] reset, [$c_2$] reset
[$c_0$] ring, [$c_1$] ring, [$c_2$] ring

# Enriched models to HMI-LTS

- System model



- Mental model



- The transformation preserves the developed algorithms

# Conclusion

- An enriched model for system and mental model
- Translation from ADEPT models (to be automated)
- Reverse translation from HMI-LTS to ADEPT to be done