AirborneCPS: A Simulator for Functional Dependencies in Cyber Physical Systems
A Traffic Collision Avoidance System Implementation

William Cook
Andrew Driscoll
Bastian Tenbergen

Department of Computer Science,
State University of New York at Oswego, USA
What are Cyber Physical Systems?

Functional Dependencies in CPS
Simulation of CPS Dependencies
AirborneCPS Technical Implementation
Summary & Outlook
Cyber Physical Systems (CPS) are a “novel” system type. CPS monitor physical values with sensors and act upon them using actuators like Embedded Systems.

CPS communicate with other systems like “Internet-of-Things”-things. CPS achieve a common goal that each individual system cannot achieve on its own.

We call this functionally dependent CPS.
Comparison to Embedded Systems

An Adaptive Cruise Control (ACC) maintains safe speed and distance to a vehicle ahead.

Suppliers build ES with OEMs in mind. **With a specific context in mind.** Once the ES is deployed, the **context will never change**.

**Assumptions** are made but **fail in case of dynamic functional dependence.**
Functional Dependence at Runtime

The Collaborative Adaptive Cruise Control (CACC) communicates with other CACCs to negotiate speed to optimize traffic flow.

Runtime interactions cannot easily be predicted at design time:

- which type and model of ACC is another vehicle equipped with?
- Is that ACC collaborative (or possibly some legacy system)?
- Are the communication protocols safely compatible?
- What if the driver chooses to ignore the CACC or does something stupid?

Open Contexts, Runtime Adaptiveness, and Human-in-the-Loop interaction pose issues for development. To investigate this, we will simulate runtime behavior.
What are Cyber Physical Systems?

**Functional Dependencies in CPS**

Simulation of CPS Dependencies

AirborneCPS Technical Implementation

Summary & Outlook
## Functional Dependence Types in CPS:
(according to [3, 15])

<table>
<thead>
<tr>
<th></th>
<th>Static</th>
<th>Dynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Homogeneous</strong></td>
<td>The CPS network is composed of a <strong>fixed number of individual CPS</strong> and each CPS has a <strong>known feature set</strong>.</td>
<td>The CPS network forms <strong>new connections at runtime</strong> with nodes possessing a <strong>known feature set</strong>.</td>
</tr>
<tr>
<td><strong>Example:</strong></td>
<td><strong>prosumer architectures</strong> [16].</td>
<td><strong>automated traffic regulation</strong> [17], <strong>smart cities</strong> [18].</td>
</tr>
<tr>
<td><strong>Heterogeneous</strong></td>
<td>The CPS network is composed of a <strong>fixed number of individual CPS</strong>, but the individual CPS devices have <strong>different feature sets</strong>.</td>
<td>The CPS network forms <strong>new connections at runtime</strong> with nodes possessing an <strong>unknown feature set</strong>.</td>
</tr>
<tr>
<td><strong>Example:</strong></td>
<td><strong>Industry-4.0-applications, IoT</strong> [19].</td>
<td><strong>CACC</strong> [4, 5], <strong>TCAS</strong>.</td>
</tr>
</tbody>
</table>

**AirborneCPS: A Simulator for Functional Dependencies in CPS**

© Bastian Tenbergen
What are Cyber Physical Systems?

Functional Dependencies in CPS

**Simulation of CPS Dependencies**

AirborneCPS Technical Implementation

Summary & Outlook
Case Example: Traffic Collision Avoidance System

**Purpose:**
Detect other aircraft on collision course, warn crew, and compute evasive action.

*Why TCAS?*
- Airborne collision avoidance implies functional dependency
- As aircraft types differ, so do TCAS implementations
- Standardization, but it only goes so far
- Readily available simulation platform, easily extendable
- We can simulate all types of functional dependence...

\[ r(t) = \|s(t)\| = \sqrt{\|s\|^2 + 2s \cdot v + t^2 \|v\|^2} \]

The range between the aircraft at any time \( t \) is given by

\[ \dot{r}(t) = \frac{s \cdot v + t \|v\|^2}{\|s(t)\|} \]
## Simulating Functional Dependence

<table>
<thead>
<tr>
<th>Homogeneous</th>
<th>Static</th>
<th>Dynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple <strong>TCAS equipped aircraft</strong> enter each other’s protection volume during flight.</td>
<td></td>
<td>All <strong>TCAS</strong> are of the <strong>same type</strong> and a known number of <strong>aircraft</strong> participate in the collision scenario.</td>
</tr>
<tr>
<td><strong>Example:</strong> Random traffic threat during climb or descending flight.</td>
<td><strong>Example:</strong> Multiple autonomous drones fly in formation.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heterogeneous</th>
<th>Static</th>
<th>Dynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple aircraft enter each other’s protection volume, but <strong>some aircraft are not TCAS equipped</strong>.</td>
<td>Multiple <strong>aircraft</strong> equipped with TCAS are interacting with one aircraft without TCAS.</td>
<td></td>
</tr>
<tr>
<td><strong>Example:</strong> Private plane with TCAS encounters an ultra-light plane.</td>
<td><strong>Example:</strong> Military aircraft intercept and escort a hostile intruder.</td>
<td></td>
</tr>
</tbody>
</table>

We can simulate all types of functional dependence.
What are Cyber Physical Systems?

Functional Dependencies in CPS

Simulation of CPS Dependencies

**AirborneCPS Technical Implementation**

Summary & Outlook
AirborneCPS: A Simulator for Functional Dependencies in CPS

Youtube Channel:
What are Cyber Physical Systems?

Functional Dependencies in CPS

Simulation of CPS Dependencies

AirborneCPS Technical Implementation

Summary & Outlook
Cyber-Physical Systems operate in an open world

CPS operate in the real world, which constantly changes, e.g., through dynamic network allocation.

Functional Dependencies in CPS Networks
homogeneous vs. heterogeneous / dynamic vs. static

How can Functional Dependencies be leveraged at design time and predicted at runtime?

AirborneCPS is a free simulation tool to aid identification of undesired functional dependencies at runtime by simulating different interaction scenarios... but it’s work in progress.

Thanks for your Attention and Feel Free to Ask Stuff