Abstract

The purpose of most engineering activities is to create a system that satisfies needs of a customer and that satisfies business objectives. However, the engineering world is technical oriented, where technical decisions tend to be made on technical trade-offs. The business and customer worlds are social and economical by nature. One of the objectives of Systems Architecting is to make design decisions in the technical world that are appropriate in the social and economical world.

Our research first of all tries to understand the current practice. The longer term goal is to enhance the current practice such that we can teach methods and techniques that actually improve current practice. We use the CAFCR model as a model to understand current practice and as model to develop methods and techniques.
Distribution

This article or presentation is written as part of the Gaudi project. The Gaudi project philosophy is to improve by obtaining frequent feedback. Frequent feedback is pursued by an open creation process. This document is published as intermediate or nearly mature version to get feedback. Further distribution is allowed as long as the document remains complete and unchanged.

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version: 0.1
Coordinates of the Speaker

Høgskolen i Buskerud (HiBu)
Buskerud University College (BUC)

Embedded Systems Institute (ESI)

BUC
Kongsberg
ESI
Eindhoven
Høgskolen i Buskerud (HiBu)
Buskerud University College (BUC)
Embedded Systems Institute (ESI)
Industrial + Academic Experience

- Philips HealthCare
- ASML
- Philips Research
- ESI
- Buskerud
- HBV
- HSN
- USN

1980 - 2010

- Industrial experience
  - time pressure
  - pragmatics
  - sales
  - cost constraints
  - products
  - lots of people

- Research academic
  - reflection
  - evidence
  - exposure
  - education

Gaudí

Systems Architecting research close to industrial companies
Introduction

1. SE research
   - global SE trends
   - research agenda

2. CAFCR
   - example of an SE method

3. Replisaurus
   - at BUC in Kongsberg

4. Status

Summary
# Today’s Industrial Trends

<table>
<thead>
<tr>
<th>Trends</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required time to market</td>
<td>Overview</td>
</tr>
<tr>
<td>Development cost</td>
<td>Feature interaction</td>
</tr>
<tr>
<td>Features</td>
<td>Complexity</td>
</tr>
<tr>
<td>Performance expectations</td>
<td>Amount of software</td>
</tr>
<tr>
<td>Number of products</td>
<td>Integration effort</td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
</tr>
<tr>
<td></td>
<td>Uncertainty</td>
</tr>
<tr>
<td></td>
<td>Dynamics</td>
</tr>
</tbody>
</table>

- **Release cycle time**: years → months
- **Openness**: interoperability
- **Hype and fashion**: globalization use
- **Globalization in development and logistics**: dynamics

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Buskerud research agenda as graph

Systems Engineering

- trends
  - time to market
  - dev. cost
  - features
  - performance expectations
  - number of products
  - release cycle time
    - years
    - months
  - openness
  - interoperability
  - hype and fashion
  - globalization use
  - globalization in development and logistics

- consequences
  - overview
  - feature interaction
  - complexity
  - amount of software
  - integration effort
  - reliability
  - uncertainty
  - dynamics

Multi-disciplinary design
- system modeling and analysis
- system design methods

Reliability / Robustness
in harsh environments

Innovation
- Responsiveness to change

Capturing core know-how
- DR

Capturing customer understanding
- KDA

Confidence level
- KA

Change analysis
- Maritime

SW in system
- FMC

Shopfloor automation
- VAN

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Industry as Laboratory

source of inspiration
application playground
industry

challenging problems
apply new engineering methods
research
improve
evaluate

hypothesis

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Dissemination and research partners

Kongsberg Industry Domains

- SubSea
- Defence
- Manufacturing
- Maritime

Generalization and consolidation to facilitate use in other domains

Single domain research focus on industrial problem

Multi-domain research and expertise

Reliability / Robustness in harsh environments

Innovation / Responsiveness for change
Method Example: CAFCR

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Summary
The “CAFCR” model

What does Customer need in Product and Why?

Customer What
Customer How
Application Functional Conceptual Realization

Product

Product How

Customer objectives

drives, justifies, needs

enables, supports
Integrating CAFCR

What does Customer need in Product and Why?

Customer What
Customer How
Product What

C - Customer objectives
A - Application
F - Functional
C - Conceptual
R - Realization

context understanding
intention
objective driven

opportunities
constraint awareness
knowledge based

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CAFCR can be applied recursively

System (producer) 
Customer 
Business Drives
Enables 

Customer's 
Customer Business

Consumer

Drives

Enables

larger scope has smaller influence on architecture

Value Chain

Enables

Drives

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CAFCRrecursion
CAFCR+ model; Life Cycle View

Customer objectives
Application
Functional
Conceptual
Realization

Operations
Development
Maintenance
Manufacturing
Upgrades
Installation
Life cycle
Sales, service, logistics, production, R&D

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BCAFCRplusLifeCycle
Quality needles as generic integrating concepts

<table>
<thead>
<tr>
<th>Customer objectives</th>
<th>Application</th>
<th>Functional</th>
<th>Conceptual</th>
<th>Realization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

- Safety
- Usability
- Safety
- Evolvability

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QNneedles
## Security as example through all views

<table>
<thead>
<tr>
<th><strong>Customer objectives</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>sensitive information</td>
</tr>
<tr>
<td>trusted</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Application</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>selection</td>
</tr>
<tr>
<td>classification</td>
</tr>
<tr>
<td>people</td>
</tr>
<tr>
<td>information</td>
</tr>
<tr>
<td>authentication</td>
</tr>
<tr>
<td>badges</td>
</tr>
<tr>
<td>passwords</td>
</tr>
<tr>
<td>locks / walls</td>
</tr>
<tr>
<td>guards</td>
</tr>
<tr>
<td>administrators</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Functional</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>functions for</td>
</tr>
<tr>
<td>administration</td>
</tr>
<tr>
<td>authentication</td>
</tr>
<tr>
<td>intrusion detection</td>
</tr>
<tr>
<td>logging</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Conceptual</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>cryptography</td>
</tr>
<tr>
<td>firewall</td>
</tr>
<tr>
<td>security zones</td>
</tr>
<tr>
<td>authentication</td>
</tr>
<tr>
<td>registry</td>
</tr>
<tr>
<td>logging</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Realization</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>specific</td>
</tr>
<tr>
<td>algorithms</td>
</tr>
<tr>
<td>interfaces</td>
</tr>
<tr>
<td>libraries</td>
</tr>
<tr>
<td>servers</td>
</tr>
<tr>
<td>storage</td>
</tr>
<tr>
<td>protocols</td>
</tr>
</tbody>
</table>

### desired characteristics, specifications & mechanisms

- social contacts
- open passwords
- blackmail
- burglary
- fraud
- unworkable procedures

- missing functionality
- wrong quantification

- holes between concepts

- bugs
  - buffer overflow
  - non encrypted storage
  - poor exception handling

### threats
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Summary
The Copper Printer

courtesy Replisaurus
www.replisaurus.com

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www.replisaurus.com

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REPLIpictures
ECPR technology replaces 6 process steps by 1 step
Overview of the different scopes

Copper cell
- clean
- sensors
- optics
- process chamber
- frame
- optics stage
- wafer stage
- doors
- pre-fill
- load master
- load wafer
- flip

Copper printer

customer fab

chip design
- mask production

semiconductor company
- metrology
- process control
- logistics
- infrastructure
- other cells
Customer key driver graph

- Pattern quality
  - Pattern resolution
  - Accuracy overlay
- Design enabling
  - E.g. CD, separation
  - Early delivery vs volume production
- Cost per layer
- Environmental impact
  - Pattern quality
  - Cost per layer
  - Environmental impact
  - Design enabling
  - Early delivery vs volume production

Partial graph:
- Many nodes and connections are not shown

-- Electric power
-- Clean water
-- Elyte
-- N2, air
-- Disposal water, air

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Process flow at fab level, from inspection until testing

1. inspection
2. seed sputter
3. Cu print
4. seed etch
5. coat/develop dielectrics
6. exposure or CMP for polymer vias
7. E-test

<table>
<thead>
<tr>
<th>throughpout in minutes</th>
<th>wafer</th>
<th>FOUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. inspection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. seed sputter</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>3. Cu print</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>4. seed etch</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>5. coat/develop dielectrics</td>
<td>3..4</td>
<td>50</td>
</tr>
<tr>
<td>6. exposure or CMP for polymer vias</td>
<td>1..2</td>
<td>30</td>
</tr>
<tr>
<td>7. E-test</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

target spec

dual layer only

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Work flow in the Copper Printer

1. Loading Master & substrate
2. Align
3. Move to proximity
4. Process incl. rinse & dry
5. Move substrate to unloading position
6. Open doors
7. Unloading Master & substrate
1. Close doors
Formula of printer throughput time

\[ t_{\text{print}} = t_{p,\text{prepare}} + t_{p,\text{align}} + t_{\text{chamber}} \text{ (thickness)} + t_{p,\text{finalize}} \]

1. Close doors
2. Align \[ t_{\text{align}} \]
3. Move to proximity
4. Process \[ t_{\text{chamber}} \]
5. Move substrate unloading position
6. Open doors

\[ t_{\text{prepare}} = t_{\text{close doors}} + t_{\text{move to proximity}} \]

\[ t_{\text{finalize}} = t_{\text{move to unload}} + t_{\text{open doors}} \]

\[ t_{\text{print}} = t_{p,\text{overhead}} + C_{\text{transfer}} \ast \text{thickness} \]

*note: original diagram was annotated with actual performance figures for confidentiality reasons these numbers have been removed*
Optical path to measure marker position

- Wafer
- Microscope
- Camera

#pixels ~ 5M

Pixel resolution versus maximum Field of View read-out and processing time

Measurement accuracy determines required resolution.

Optical resolution and magnification determine displacement.

Displacement determines required Field of View.
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   - SE research at BUC in Kongsberg

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Summary
Alternate Research Agenda Visualization

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RCBEresearchSpace

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Actual Projects 2008-2010

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RCBEprojects
Small Dots in Huge Research Space

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RCBEP强悍Zoom
Introduction

1. SE research
   - global SE trends
   - research agenda
   - industry as laboratory

2. CAFCR
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3. Replisaurus
   - Cu printer: understand design in fab context
   - small dots in huge research space

4. Status
   - at BUC in Kongsberg

Summary

- faster
- more complex
- more integration
- modeling & analysis
- robustness
- innovation

multi-view
goals-means
iteration
recursion