From Autonomous Subsystems to Integrated System

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Abstract

Systems evolve from mostly mechanical or physical devices into multi-disciplinary integrated systems. This evolution takes years or decades. The evolution occurs simultaneously with changes in the markets and in the organization. We describe this evolution and illustrate it with a X-ray systems and wafersteppers.

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Evolution of X-ray Systems

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September 9, 2018
FAIRxray Timeline
..~1980
many independent modules most Philips, some 3rd party
sales: all configurations are possible
system integration (SI) in factory
many adaption boxes
SI is mostly electro mechanical
innovation elapsed time many years (f.i., 10 years for new imaging chain)
Organization in 1980

innovation departments
- Roentgen Electronics Laboratory
- Mechanical Electronics Laboratory
- Physics Technical Laboratory

facilitating departments: drawing office; construction office; workshops
Geographical locations in 1980

- **Germany**
  - Factory and warehouse
  - R&D
  - Marketing sales management

- **Netherlands**
  - Factory and warehouse
  - R&D
  - Road
  - Distance
  - Marketing sales management

- **France**
  - Factory and warehouse
  - R&D
  - Marketing sales management

- **Italy**
  - Factory and warehouse
  - R&D
  - Marketing sales management

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Staff in 1980

small teams

3 key persons:
   application
   senior designer
   cardiologist (outside Philips)

application and domain technology implicit in most staff

staffing mostly domain technology driven
..~1985
autonomous subsystems: Geo Acquisition Imaging X-ray generation

sales: preferred configurations; arbitrary configurations are more expensive
system integration (SI) in R&D
  SW in all subsystems
  SI is is electro mechanical and configuration parameters
innovation elapsed time several years (f.i., 2 years for digital imaging chain)
# Organization in 1985: Product/Business Oriented

<table>
<thead>
<tr>
<th>Product</th>
<th>Successful Applications</th>
<th>Little Synergy or Commonality</th>
<th>Struggling with Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>mammography</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>surgery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>radiography</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- Geo
- Acquisition
- Imaging
- X-ray generation

**URF**

**Vascular**

**Cardio**

## Notes

- Most products: successful application oriented, little synergy or commonality, struggling with software.

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FAixray1985organization
medium sized teams

strong subsystem focus

software depends on few good SW engineers (often with HW background)

project leader is also system designer

significant System Integration effort
Cardio and Vascular are merged. Digital imaging gets dominant
Geographical locations in 1990

Germany
- factory and warehouse
- R&D
- marketing sales management

USA
- R&D
- marketing sales

Netherlands
- factory and warehouse
- road
- R&D marketing management
- corporate management
matrix organizations within product groups:
  mechanical
electrical
  software

application and domain technology know how diluted

software content is significant

test and validation time is significant (> 1 year)

senior designer ~ = system designer
Common X-ray components (imaging, generation, collimators)

Common digital infrastructure (workstations, networks, printers)

- URF
- CT scanner
- communication standard
  - DICOM
- common digital systems
  - printer
  - workstation
- cardio/vascular
- MR scanner
Common components are organized as separate groups:
X-ray and PMS-wide
2000: Introduction of central System Control

New: system control = industrial PC + Windows XP + 4 Mloc + 3rd party SW

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Catherization Laboratory integrates many systems and is heavily connected to other health care departments and systems.

MR scanner
CT scanner
Cardiology
Radiology
Hospital
Information System
PACS
PC's
catherization lab
tip positioning
ultra sound
monitoring
kV mA
## Characterization per Phase

<table>
<thead>
<tr>
<th></th>
<th>Electro-mechanical Components</th>
<th>Autonomous Subsystems</th>
<th>Synergy</th>
<th>System Control</th>
<th>System of Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System</strong></td>
<td>emerging</td>
<td>R&amp;D integration</td>
<td>R&amp;D integration</td>
<td>hierarchy</td>
<td>emerging</td>
</tr>
<tr>
<td><strong>Dominant Concern</strong></td>
<td>modularity</td>
<td>configuration management</td>
<td>synergy</td>
<td>synergy</td>
<td>market value</td>
</tr>
<tr>
<td><strong>Staff</strong></td>
<td>all round</td>
<td>all round + gurus</td>
<td>disciplines M, E, I + grey hairs</td>
<td>disciplines M, E, I + System</td>
<td>disciplines M, E, I + System</td>
</tr>
<tr>
<td><strong>Organization</strong></td>
<td>domain labs</td>
<td>products subsystems</td>
<td>matrix</td>
<td>layered matrix</td>
<td>+ network</td>
</tr>
<tr>
<td><strong>Size R&amp;D</strong></td>
<td>tens</td>
<td>hundred</td>
<td>several hundred</td>
<td>hundreds</td>
<td></td>
</tr>
</tbody>
</table>
Control Hierarchy of a Waferstepper

- Laser
- Illuminator
- Lens
- Measurement
- C&T
- Reticle Stage
- Reticle Handler
- Wafer Stage
- Wafer Handler

System control coordination

Vertical motion
Horizontal motion

Ethernet

VME

Vertical motion
Horizontal motion
Frequency of Control Actions

- SW sampling per die
- per wafer
- per batch
- per day maintenance

10^{-3} 1 10^3 10^6

seconds

trend with increasing performance requirements
Evolution of System Control

1990
150 kloc

2000
2000 kloc
Consequences of Evolution

- Complexity
  - loss of overview (150kloc fits in 1 mind, 2Mloc not
  - (more than?) exponential increase of coupling
  - 1:1 relation HW:SW becomes n:m relation

- Performance and functionality demands

- Reliability
  - threatens paradigm shift!

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