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.
Evolution of X-ray Systems

From Autonomous Subsystems to Integrated System

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June 21, 2020
FAI\textregistered{}xray Timeline
Diagnostic X-ray system 1980

..~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

facilitating departments:
  drawing office; construction office; workshops

Physics
Technical
Laboratory

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Geographical locations in 1980

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

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

- Italy

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

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FAxray1985system

Systems 1985..1995

..~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 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>mammography</th>
<th>surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>radiography</td>
<td></td>
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</tbody>
</table>

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

Most products:
- Successful application oriented
- Little synergy or commonality
- Struggling with software
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
Synergy drive ca 1990

Cardio and Vascular are merged. Digital imaging gets dominant

Legend

- Geo
- Acquisition
- Imaging
- X-ray generation

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Geographical locations in 1990

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

- **USA**
  - R&D
  - marketing
  - sales

- **Netherlands**
  - factory and warehouse
  - R&D
  - marketing management
  - corporate management

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Staff in 1990

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)
Organization 1995..2000: Additional Synergy Layer

Common components are organized as separate groups:
- X-ray and PMS-wide

**Product groups; application/market oriented**
- cardio/vascular
- URF
- RAD
- Surgery

**X-ray component suppliers**
- Imaging
- X-ray generation

**Common digital infrastructure supplier**
- HIS
- RIS
- viewing
- archiving
- communication
2000: Introduction of central System Control

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

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FAxray2000system
Catheterization Laboratory integrates many systems and is heavily connected to other health care departments and systems.
# Characterization per Phase

<table>
<thead>
<tr>
<th>system</th>
<th>emerging</th>
<th>R&amp;D integration</th>
<th>R&amp;D integration</th>
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<th>emerging</th>
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<tbody>
<tr>
<td>dominant concern</td>
<td>modularity</td>
<td>configuration management</td>
<td>synergy</td>
<td>synergy</td>
<td>market value</td>
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<tr>
<td>staff</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>
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<td>organization</td>
<td>domain labs</td>
<td>products subsystems</td>
<td>matrix</td>
<td>layered matrix</td>
<td>+ network</td>
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<td>size R&amp;D</td>
<td>tens</td>
<td>hundred</td>
<td>several hundred</td>
<td>hundreds</td>
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</tbody>
</table>

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Block Diagram of a Waferstepper

- Laser
  - Light source
- Illuminator
  - Beam shaping
- Reticle stage
  - Positioning
- Lens
  - Projection
- Wafer stage
  - Positioning
- Reticle handler
  - Input/output
- Wafer handler
  - Input/output
- System control
  - Coordination
- Measurement
  - Alignment, levelling
- C&T
  - Contamination, temperature

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FAIwaterstepperSubsystems
Control Hierarchy of a Waferstepper
Frequency of Control Actions

trend with increasing performance requirements

<table>
<thead>
<tr>
<th>Action</th>
<th>Frequency</th>
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<tbody>
<tr>
<td>SW sampling per die</td>
<td>$10^{-3}$</td>
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<tr>
<td>per wafer</td>
<td>1</td>
</tr>
<tr>
<td>per batch</td>
<td>$10^3$</td>
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<tr>
<td>per day preventive maintenance</td>
<td>$10^6$</td>
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seconds
Evolution of System Control

1990
150 kloc

2000
2000 kloc

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FAcontrolEvolution
Consequences of Evolution

- 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

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