Tutorial Software as Integrating Technology in Complex Systems

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Abstract

This tutorial describes the integrating value of software in complex systems. The extensive use of software technology to integrate other technologies has a significant impact on the product characteristics and on the product creation organization and process. This tutorial provides insight in the relation between software and the system, and it provides insight in the consequences for the product and the organization. Some recommendations are provided to cope with these consequences.
Case: the waferstepper and it’s context

The role of software in general

Levels of abstraction

Software -> System Functionality and Qualities

Requirements perspective

Evolution and Growth

Why do we always have problems with software?

Conclusion
What is a waferstepper
From stepping to scanning

**stepper:** static exposure of field

**scanner:** dynamic exposure through slit

- step

---

**Stepper:**
- Wafer
- Reticle
- Slit

**Scanner:**
- Wafer
- Reticle
- Slit

- 250 mm/s

---

**Legend:**
- $v_x$
- $v_y$
- t
- Expose
- Step
Key specifications waferstepper

imaging

130 nm

line width

10 nm

critical dimension

45 nm overlay

alignment

45 nm overlay

130 nm

10 nm

critical dimension

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ASML key Specifications
Moore's law
Exercise 1, 10 minutes

Make a 3 picture description (What, How, biggest challenge) of your own system.
Fab Context of Waferstepper
Business Context

yield

value of performance (MHz)

CD control

key driver trade-off

other players:
- equipments vendors
- system integrators
- lease companies
- fab designers
- consultants
- mask makers
- resist makers
- wafer makers
- OEM’s: laser
- intimate partners: lens

business models of the customer:
- design houses
- foundries
- vertical integration

Limited number of customers;
Many systems per customer
Human Context: Stakeholders

'external'

- customer
- purchaser
- decision maker
- user
- operator
- maintainer

'other'

- government
- customer's customer
- banks, insurance

"internal"

- managers
  - business manager
  - marketing manager
  - product manager
  - operational manager
  - project leader
  - sales manager
  - quality manager
  - logistics manager
  - line manager
  - technology manager

- engineers
  - system engineers
  - experts
  - manufacturing engineers
  - customer support

-suppliers
  - component manufacturer
  - outsourced design
Multitude of Disciplines

- Lithography
- Mechanics
- Dynamics
- Imaging
- Optics
- Measurement
- Construction
- Construction materials
- Optical materials
- Sensors
- Interferometers
- Robots
- Capacitive sensors
- Hall sensors
- Real-time executives
- Digital signal processing
- Pre-amplifiers
- Analog signal processing
- Uniformity
- Frequency
- Pulse timing
- Energy
- Dose control
- Measurement
- Gratings
- Lasers
- Lamps
- Lens
- Coatings
- Reflection
- Transmission
- Temperature
- Sensitivity
- Stiffness
- Modes
- Motors
- Actuators
- Servo's
- C&T
- Light sensor
- Digital infrastructure
- Analog infrastructure
- Dose sensor
- Home sensors
- SW control
- UV sensitivity
- Transmission
- Reflection
- Cooling
- Vacuum clamping
- Mirrors
- Measurement lasers
- Capacitive sensors
- Hall sensors
- Real-time executives
- Digital signal processing
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- Servo's
- C&T
- Light sensor
- Digital infrastructure
- Analog infrastructure
- Dose sensor
- Home sensors
- SW control
- UV sensitivity
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INSEcomplexity
Symptom: Delays appear during Integration

Do you have any design issues for the design meeting?

The default answer is: No.

During integration numerous problems become visible.

scheduled closing date

realized closing date

delay

Integration and test
Exercise 2, 10 minutes

Make a 3 picture description (Application context, Value chain, technologies) of your own system.
Relative Contribution of SW

![Graph showing the relative contribution of SW, electronics, mechanics, and physics/chemistry, etc. over time from 1970 to 2000. The graph illustrates an increasing trend in the relative effort for electronics, mechanics, and SW, with physics/chemistry, etc. showing a decreasing trend.](image-url)
Control Hierarchy along Technology axis

- **Control**
  - Human user
  - Application SW
  - Control SW
  - Digital electronics
  - Analog or power electronics
  - Mechanical device
  - Optical device
  - Sensor

- **Feedback**
  - Local automation or safety

**Legend**
- 
- 
- 

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RSWcontrolHierarchy
Characterization of disciplines
Exponential Pyramid, from requirement to bolts and nuts

- **$10^0$**
  - number of details
  - system requirements
- **$10^1$**
  - design decisions
- **$10^2$**
  - parts connections
  - lines of code
- **$10^3$**
  - multi-disciplinary system
- **$10^4$**
  - mono-disciplinary system
- **$10^5$**
  - research focus
- **$10^6$**
  - system
- **$10^7$**
  - mono-disciplinary
Waferstepper Example

overlay: 45nm
CD control: 10nm
productivity: 100Wph

source
reticule
lens
wafer
10 Mloc

10 Mloc
From Components to System Qualities

system qualities

prepare
align and calibrate
scan and expose
transport wafer
transport reticle
functions

laser
lens
stages
handlers
electronics infra
metro frame
subsystems

source
mirrors
fiducials
lens elements
flaps
air showers
frames
motors
sensors
robot
bolts
nuts
air mounts
PCBs
ICs
cables

OS
database
user interface
TCP/IP
comms package

overlay
CD control
productivity

components
Role of Software

SW implements functionality
determines emerging qualities

components

subsystems

functions

system qualities
Exercise 3, 10 minutes

Make a toplevel decomposition of the software in your system and estimate the amount of software of the constituting parts
When SW engineers demand "requirements", then they expect \textit{frozen} inputs to be used for the design, implementation and validation of the software.
**System vs Software Requirements**

![Diagram showing the comparison between system and software requirements. The diagram uses a logarithmic scale to illustrate the number of details at different levels.](image-url)
Why is the Software Requirement Specification so Large?

- software subsystem
- user interface
- system behavior
- operational choices
- synergy, tools, ...
- limited computing resources
- control of physical subsystems: sensors, actuators
And why is it never up-to-date?
Exercise 4, 2 minutes

How many pages are in your Software Requirements Specification?
Control Hierarchy of a Waferstepper
Frequency of Control Actions

trend with increasing performance requirements

- SW sampling per die: $10^{-3}$
- per wafer: 1
- per batch: $10^3$
- per day: $10^6$
- preventive maintenance

seconds
Evolution of System Control

- User interface
- Automation interface
- Monitoring and optimization
- Metro
- Job control
- Exposure control
- Data management
- Dynamic calibration
- Production and installation support
- Infrastructure
- Feedforward
- Monitoring

<table>
<thead>
<tr>
<th>Year</th>
<th>Code Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>150 kloc</td>
</tr>
<tr>
<td>2000</td>
<td>2000 kloc</td>
</tr>
</tbody>
</table>
Consequences of Evolution

- **Loss of Overview**: (150kloc fits in 1 mind, 2Mloc not)
- **Exponential Increase of Coupling**: (more than?)
- **1:1 Relation HW:SW becomes n:m relation**

**Autonomous Subsystems** → **Paradigm Shift!** → **Integrated System**

**Performance and Functionality Demands** → **Complexity** → **Reliability**
Exercise 5, 10 minutes

Visualize the (SW) evolution of your system. What is your current phase?
Different Focus of Software and System

**System engineering focus**
- qualities
- productivity
- image quality
- reliability

**concepts**
- domain requirements
- models

**concerns**
- integral design (quality, balance)
- system context
- lifecycle
- operational processes

**education**
- principles
- heuristics
- analysis and synthesis
- processes

**SW engineering focus**
- qualities
- functionality
- maintainability
- variability

**concepts**
- structure
- (generic) mechanisms

**concerns**
- configuration management
- release procedure
- tools
- SW processes
- SW problems, change requests

**education**
- languages
- operating systems
- algorithms
- formal methods
Caricature of a SW Architecture

Application

Property editor

NameSpace server

Event manager

Transparant Communication

Registry

Monitor

Compliance profile

Persistent Storage

Plug-in framework

Device independent format

Session manager

Broker

Spool server

Queue manager

Resource scheduler

Configurable pipeline

Compliance profile

Application

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Compliance profile

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Plug-in framework

Device independent format

Session manager

Broker

Spool server

Queue manager

Resource scheduler

Configurable pipeline

Compliance profile
Caricature of Physics Systems View

laser
pulse-freq, bw, wavelength, ..
illuminator
uniformity
sensor
reticle
lens
aerial image
wafer
NA abberations
transmission
wafers
reticle
aerial image
NA abberations
transmission
Relation SW and Physics

- Laser
- Illuminator
- Sensor
- N.A.
- Abberations
- Transmission
- Uniformity
- Reticule
- Aerial Image
- Lens
- Pulse-freq, bw, wavelength, ..
- Measure
- Adjust
- Calibrate
- Analyse
- Process
- Log
- Control

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TSAITphysicsAndSW
Symptoms of too isolated SW efforts

**Symptoms**

- SW people are clustered together
- SW is alpha tested before system integration
- SW team uses own specification and design process
- SW specification is in SW jargon or formalism

**Countermeasures**

- Colocation per function, subsystem or quality
- Continuous system integration
- Higher level processes are shared
- Interaction between SW, HW and system engineers
Exercise 6, 5 minutes

What is the degree of integration or isolation of SW in your organization?
Different Mindsets and Characteristics

**System**
product: sellable self-sustained entity operating in a broader context

**different focus:**
"qualities
"concerns
"concepts
"education

**HW engineering**
tangible
concrete
goods flow costs & lead times
physics laws

**SW engineering**intangible
abstract
no goods flow costs
"everything is possible"

**inherent performance reliability**
**actual performance reliability**