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.
Program

- 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
Twinscan AT1100
What is a waferstepper

source
reticle
lens
wafer
From stepping to scanning

**stepper:** static exposure of field

**scanner:** dynamic exposure through slit
Key specifications waferstepper

imaging

alignment

130 nm

line width

45 nm overlay

10 nm

critical dimension
Moore’s law
Everything influences overlay

Overlay Influence Diagram.
(Maarten Bonnema, 19-3-1999)

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ASMLOverlayInfluenceDiagram
Exercise 1, 10 minutes

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

- devices
- wafer
- waferstepper
- resists
- metrology
- matching
- contamination
- fab logistics
- fab automation
- SPC
- yield optimization
- inspection and monitoring
- fab cost
- fab model
- fab infrastructure
- operator
- utilization
- semiconductor design
- reticule production
- reticules
- process
- tracks
- production
- logistic
- maintenance
- utilization
- fab layout
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

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INSEstakeholders
Multitude of Disciplines
Complexity of Waferstepper Context

market, business

fab context

multitude of disciplines

stakeholders

value of performance (MHz)

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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
Make a 3 picture description (Application context, Value chain, technologies) of your own system.
Control Hierarchy along Technology axis

- human user
  - application SW
    - control SW
      - digital electronics
        - analog or power electronics
          - mechanical device
          - optical device
          - sensor

Legend:
- local automation or safety
Characterization of disciplines
Exponential Pyramid, from requirement to bolts and nuts

- System
- Multi-disciplinary
- Mono-disciplinary
- Parts
- Connections
- Lines of code
- Design decisions
- Requirements
- System

number of details

research focus
Waferstepper Example

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

source
reticule
lens
wafer
10 Mloc
From Components to System Qualities

**Components**
- source
- mirrors
- fiducials
- lens elements
- flaps
- air showers
- frames
- motors
- sensors
- robot
- bolts
- nuts

**Subsystems**
- transport wafer
- laser
- lens
- stages
- handlers
- electronics infra
- metro frame

**Functions**
- prepare
- align and calibrate
- scan and expose
- transport wafer
- transport reticle

**System Qualities**
- overlay
- CD control
- productivity

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ATlayers
Role of Software

- Components
- Subsystems
- Functions
- System qualities

SW implements functionality and determines emerging 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 *frozen* inputs to be used for the design, implementation and validation of the software.
System vs Software Requirements

- System Requirements
  - Multi-disciplinary
  - Mono-disciplinary

- Software Requirements

Number of details vs. System vs Software Requirements
Why is the Software Requirement Specification so Large?

software subsystem
user interface
system behavior
limited computing resources
control of physical subsystems: sensors, actuators
operational choices
synergy, tools, ...

software subsystem
limited computing resources
control of physical subsystems: sensors, actuators
operational choices
synergy, tools, ...

user interface
system behavior
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

- 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

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FAIcontrolHierarchy
Frequency of Control Actions

**trend with increasing performance requirements**

- **SW sampling per die**
  - $10^{-3}$ seconds

- **per wafer**
  - 1 second

- **per batch**
  - $10^3$ seconds

- **per day maintenance**
  - $10^6$ seconds
### Evolution of System Control

<table>
<thead>
<tr>
<th>Year</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>150 kloc</td>
</tr>
<tr>
<td>2000</td>
<td>2000 kloc</td>
</tr>
</tbody>
</table>

#### Diagram:
- **User Interface**
  - Static Calibration
  - Simple Sequencer
  - Data Store

- **Automation Interface**
  - Monitoring and Optimization
  - Metro
  - Job Control
  - Exposure Control
  - Dynamic Calibration
  - Data Management

- **Infrastructure**
  - Feedforward
  - Monitoring
Consequences of Evolution

- Loss of overview: (150kloc fits in 1 mind, 2Mloc not)
- Exponential increase of coupling
- 1:1 relation HW:SW becomes n:m relation

Performance and functionality demands causes complexity, which threatens reliability.

Autonomous subsystems lead to a paradigm shift towards integrated systems.
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

- **structure**
  - (generic) mechanisms

- **concepts**

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

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

Property editor

NameSpace server

Event manager

Registry

Persistent Storage

Session manager

Broker

Transparant Communication

Monitor

Plug-in framework

Compliance profile

Device independent format

Spool server

Queue manager

Resource scheduler

Configurable pipeline

Abstraction Layer

Plug & play
Caricature of Physics Systems View

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

- Laser
- Illuminator
- Sensor
- Reticule
- Lens
- Wafer
- Aerial Image
- NA
- Abberations
- Transmission

- Measure
- Adjust
- Calibrate
- Analyse
- Process
- Log
- Control

- Pulse-freq, bw, wavelength, ..
- Uniformity
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

**counter measures**

- 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"