Dynamic Scheduling in the Laboratory
Problems and Solutions

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What is scheduling?

- Set of resources (machines, lab devices)
- Set of objects (samples) to be processed on these resources
- Find the best timing for the processing

Examples: building construction, car production, sample analyses
Scheduling on a lab work bench

Conflicts: Different objects at the same time on the same resource
→ To be solved by rearranging of time slots or usage of additional resources
The process

- **Static components:**
  - Devices with specific task(s): location, commands, material port(s), data port(s), initialization, configuration, availability, dependencies to other devices, maintenance

- **Dynamic components:**
  - Samples/wafers being processed on the devices: sample handling, sample preparation, testing
Resources

- Resources defined via capabilities:
  - Device attribute or set of device attributes

Capability → List of devices, device types, device groups
Our environment

- Production of electronic circuits on wafers (synthetic process)
  - Product = wafer = material

- Laboratory automation (analytical process)
  - Product = results = information
Requirements for the process modeling

- Existence of **activities** controlling all device attributes
- In-process control by **sensors**
- Conditional **branching**
- Availability of loops
- 24/7 operation → automated **error management**
- **Documentation** as part of the process
The activity

- Use a command to execute an operation on a device with certain capabilities.

Examples of activities:
- Device control
- Sensor readout
- Storage operation
- Documentation step
- Sample split or merge
- Program start
Design of the activities

1. Time constraints to the preceding activities
2. Time constraints to the next activities
3. Pre trigger
4. Post trigger
5. Branching to an error workflow
6. Consumables
7. Durables
8. Variables
Functionality of activities

- Scheduler relevant information
  - Timing (min / max duration)
  - Constraints and delays

- Execution relevant information
  - Commands
  - Execution parameters
  - Variables
Workflow libraries

- Problem: functional separation of tasks
  - Chemist → chemistry
  - System administrator → system control functionality

- Several activities may be combined to macros
- Handling steps included in macros
- Exchange of parameter values
- Macros reusable
Hidden transport

Legend:
Colored = transport macro
Multi position device

Problem: How can several samples utilize different slots on one device in parallel?

Solution: Scheduling algorithms has to provide this feature
Manual interactions

Problem: Unknown execution time for operations with manual interactions

Solution:

- Set maximum duration for command execution
- Use timeout mechanism
- Completion notification via push button
- Generation of post trigger “manOp_finished”
Workflows as XML schema

Root element of a concrete Workflow-Definition, contains (Sub-) Workflows and their relations.

Activity

WorkflowControl

TransportConstraint

Interface to the outside world

Structure defined in a schema

Possibility of an automated validation
Activities as part of the workflow XML schema
Working plan

Device 1
- 2
- 7-1
- 8-1
- Manual

Device 2
- 7-2
- 8-2

Device 3
- 7-3
- 8-3

No

Yes

Workflow

1
2
3
4
5
6
7
8
9
10
11
12

Time
Working plan – “no branch“
Working plan – complete
Working plan – complete

Working plan

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Yes branch
Norm branch
No branch

Yes branch
Norm branch
No branch

Yes branch
Norm branch
No branch

Yes branch
Norm branch
No branch

Yes branch
Norm branch
No branch

Yes branch
Norm branch
No branch

Workflow

Workflow
Resource reservation times

Workflow

Working plan

Time
Scheduling algorithm functionalities

- Rearrangement of sample oriented workflows to device oriented working plans considering
  - Timing restrictions
  - Activity constraints
  - Non interruptible sequences
  - Multi position devices
  - Multiple identical instruments
  - ...

- A really complex task!
Scheduling system’s functionality

- Estimate calculation time
- Calculate the working plan

In case of exceptions:
- Continue unaffected samples
- Re-schedule the working plan
- Synchronize running plan with new plan
- Activate new plan
Estimation of calculation time

Ad hoc samples introduced into the system

Legend:
1 Estimation of restart time
2 Calculation time
3 Safety buffer
Terms and definitions

- **Scheduling:**
  - Arrangement of activities over time utilizing all constraints. Activities may belong to different samples.

- **Static scheduling:**
  - All activities and constraints are defined before calculation starts.

- **Dynamic scheduling:**
  - Some activities and their constraints are added during the calculation process.
Scheduling system: time related view

- High level description of the process with capability needs
- Utilization of macro library
- Hiding of transports

- Assignment of specific devices
- Calculation of working plans
- Automated usage of multi position instruments

- Control of devices
- Result acquisition
- Error handling
Scheduling system: information related view

- Workflow library
- Scheduler
  - Workflows
  - Samples
  - Work bench control
- Static work bench description
- Dynamic work bench description
- Maintenance WFs
- Error WFs

Workflow Samples
Dispatching plans

- Ad-hoc assignment of devices to activities (first come, first serve mode)
  - Workflows are executed in parallel
  - Next activity is assigned to unused device
  - Need for a conflict resolution in case of multiple request at one time
Optimized scheduling

- Scheduling run generates a “real” working plan
  - This is “a” solution
    → Is it optimal referring the pre-specified criteria?
  - Answer is not known, because no reference exists!

- Modify calculation parameters + calculate again

- Compare result referring pre-defined criteria
- Use best working plan for execution
Result handling (1)
Intelligent device adaptor

- Results bypass scheduling system and go directly to the database (adaptor stores them)
- Storage location transferred via workflow parameters
- Error feedback separately

No re-scheduling capability initiated by result values
Result handling (2)
Pseudo device for DB access

- Pseudo device for DB
- Performs DB operations
- Checks result plausibilities

Seamless integrated error and re-scheduling handling

Remark:
Pseudo devices may be used also for complex calculations
Error handling

- Error handling hidden
- Different exceptions in various phases (expansion, scheduling, execution)
- Standard error exits in activities with connected error workflows for standard recovery features
  - “clear error message”
  - “redo command”
  - “stop processing, ask operator assistance”
  - ...

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Error workflow

- An error workflow is a workflow being initiated automatically in case of a device exception via the re-scheduling mechanism.

- Consists of activities and control operators.

  - Error
    - Instrument vendor
  - Reaction class
    - Pre-defined per installation
  - Error workflow
    - Written by system admin.
    - Defined by user during workflow generation
Summary

- Process modeling via workflows coded in XML
- Addition of sample relevant information during instantiation of workflows
- Assignment of time slots on devices to activities
- Execution of device oriented working plans
- Definition of pseudo devices for DB, ...
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