Mathematical Optimization at Siemens

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Outline

- Siemens Company – a short introduction
- Mathematics at Siemens Corporate Technology
- Assembly of printed circuit boards
- Water supply network planning
- The internet of things
- Outlook
Siemens Company
Siemens' innovations have changed the world

Industry
From the first electronic controls –
to fully automated factories

Energy
From the invention of the dynamo –
to the world's most efficient gas
turbines

Healthcare
From the first interior view of the body –
to full-body 3D scans
Siemens Company
Milestones for Three Centuries

Innovation for:
- Information and Communication
- Energy
- Industry Automation
- Mobility
- Healthcare
- Lighting Technology
- Household Appliances

1847: Werner von Siemens founded the company

1847: Telegraph
1848: Graphophone
1866: Dynamo
1879: Electrical railway
1881: Telephone switchboard
1881: Electrical streetcar
1884: Dynamo
1885: Magnetic telegraph
1889: Telegraphy
1893: Integrated circuits
1895: Tantalum lamp
1896: Telephone for energy
1905: Hicom telephony switchboard
1905: Heart pacemaker
1906: Vacuum cleaner
1912: Trafo (transformer)
1924: Traffic light
1925: Very clean silicon
1929: Vacuum tube
1931: “Hot air shower” (hair-dryer)
1935: Coax cable
1938: X-ray tube
1942: Transistor
1947: Tesla coil
1953: Computer
1958: Computer tomography scanner
1962: Thyristor
1965: Thyristor for energy
1969: Computer
1974: Computer tomography scanner
1979: Very clean silicon
1980: Integrated circuits
1982: Megabit chip
1984: HIcom telephony switchboard
1985: High temperature fuel cell
1986: High speed train ICE (300 km/h)
1988: Megabit chip
1989: High temperature fuel cell
1990: Computer
1993: Computer
1994: Computer
1995: Computer
1996: Computer
1997: Computer
1998: Computer
1999: Computer
2000: Electronic wedge brake
2000: Piezo Injection for diesel engines
2001: Computer
2002: Computer
2003: Computer
2004: Computer
2005: Computer
2006: Computer
2007: Computer
2008: Computer
2009: Computer
2010: Computer

Employees in 2005: 461,000
Sales in 2005: 75,445 Billion Euro

Information and Communication
Energy
Industry Automation
Mobility
Healthcare
Lighting Technology
Household Appliances

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Siemens Company
Almost 50,000 R&D Employees at 150 Locations
Mathematics evolves its impact most effectively if it appears as a PARTNER together with other sciences and technologies.
Research and Innovation
The Mindset

Giants …
- GUI
- Middleware
- Incorrect inputs
- External systems
- Data base
- Operating system
- 100k LOC
- Commissioning
- Bug Fixing

Dwarfs and elves
- Modeling
- Theorems and proofs
- Algorithms
- Interfaces
- Software Engineering

… and Dragons
Research and Innovation
From Modeling to Application

Modeling
Realization
Integration
Assembly of Printed Circuit Boards
Optimizing the automaton

Distribute components to all stations in order to achieve a well-balanced line

Construct short paths on the board for each head for fast placement

Select and configure nozzles for each head such that the number of placement cycles is minimized

Arrange component feeders for fast picking sequences

Comp. Types

Nozzle Types
Assembly of Printed Circuit Boards
Coherence in Systems Hierarchy

Factory
- Layout
- Dispatching and scheduling
- Staff assignment
- Material supply
- Maintenance planning

Production Lines
- Matched line configuration of machines
- Optimum component feed along the line
- Trade-off between set-up times and processing times

Machine Level
- Timing and spatial constraints of single machines
- Necessary resources behavior
- Availability
Given:

- Bipartite Graph \( G = (U \cup V, E) \) such that 
  \( (u, v) \in E \iff \) Component type \( u \) may be placed through nozzle type \( v \)
- For every node \( u \in U \) a component number \( b_u \)
- For every edge \( (u, v) \in E \) an integer variable \( y_{uv} \)
- For every node \( v \in V \) an integer variable \( x_v \)
- \( k = \) Number of nozzle positions at the placement head
- Variable \( z = \) Number of placement cycles

Nonlinear model:

\[
\begin{align*}
\text{min } z \\
\text{such that } \sum_{v \in V} y_{uv} = b_u \\
\forall v \in V : \sum_{u \in U} y_{uv} \leq zx_v \\
\sum_{v \in V} x_v \leq k \\
\end{align*}
\]

All variables nonegative integers

Runtime requirement: At most 5 ms!
Water Supply Network Planning
A Simple Network
Water Supply Network Planning
Inputs and Goals

Objectives:
1. Safe operation
2. Full supply of consumers
3. Minimal costs for water and energy
4. As few as possible pump switches

Input:
1. Contract with energy supplier
2. Demand forecast for consumers (districts)
3. Contract with other water suppliers

Required:
1. Fill levels for the reservoirs
2. Schedule for valves
3. Schedule of pump switches for the planning horizon (24h)
Water Supply Network Planning
Inputs and Goals

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Required: Schedule of pump switches for the planning horizon (24h)
Required: Fill levels for the reservoirs
Required: Schedule for valves
Water Supply Network Planning
General Setting for Optimization

- Demand forecast on a hourly basis; Planning period: 24 h
- No consideration of pressure progression
Water Supply Network Planning

Subnets

Subnet 1

Subnet 2

Subnet 3
Water Supply Network Planning
Graph Model

Subnet 1
- Feeder 1
- Supplier
- Spring
- Well
- Consumer 1

Subnet 2
- Consumer 2

Subnet 3
- Supplier
- Well
- Spring
- Consumer 1
Water Supply Network Planning
Creating pump switches

Min cost flow solutions

Schedules / fill levels

Solutions of the model have to be transformed into switching points of time for the pumps and fill level curves for the reservoirs.
Water Supply Network Planning
The Real Planning Cycle

- Initialize planning: Set current constraints
- Compute schedule: Pump switches, fill level curves
  - Optimization
- Evaluate schedule: Pressure progression
  - Simulation
- Modify specifications
- Activate schedule
Water Supply Network Planning  
The Toolset

- Siwa-Plan is a toolset for the **management** of water supply networks, including planning and control functions.

- Using Siwa-Plan, the first step is the **engineering** of the water net under consideration.

- In addition to the implementation of optimization and simulation routines, the challenge is to **generate** an appropriate optimizer and simulator.
Water Supply Network Planning
Integration Into Control Equipment

- Bürowelt / Office
- Internet/Intranet
- OS Clients / Multi-Clients
- Terminal Bus
- OSI
- Industrial Ethernet / System Bus
- PROFIBUS-DP
- PROFIBUS PA
- ET 200M Ex-I/O
- ET 200M
- ET 200S
- SIWACIT PLAN
- Service
- Engineering Station ES
- OS Server
- Service
- OPC-Server
- O&M
- @aGlance / OPC-Server
The Internet of Things
Routing Goods Like Data

Baggage handling at Beijing airport

Mail distribution centers

The Internet of Things – A public funded project *)

*) German Federal Ministry of Education and Research
The Internet of Things
Hierarchical Structure of Commissioning Systems

Hardware

IT-Structure

Leitebene

Zellenebene

Feldenebene

Aktor-Sensor-Ebene

Industrial Ethernet

AS-Interface

Mechanik, Aktorik, Sensorik

Materialfluss-Steuerung (MFR)

SPS SPS

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The Internet of Things
Basic Concepts

New controls architectures
- Migration of “Intelligence” to field level (e.g., "intelligent drives")
- Distributed controlling functions
- Vernetzung of devices at field level ("industrial ethernet")
- Web based services for the level of controls ("one homepage for every motor")

New systems architectures
- Distributed software systems
- Decentralized controls (e.g., agent technology)
- "Aware objects" (RFID, RF-based systems)
- Pervasive computing

New material flow strategies
- "Routing goods like data" (e.g., like e-mail)
- Methods of network management (e.g., IP routing) in physikal-logistic systems
OK, I have to be X-rayed next ...

Ouuh, I am skeptic. I have to work off the main baggage stream for Flight No. XYZ. I decline.

Well, I can do the job. I expect you in five minutes.

Auction
Where to localize the agents?

- At the field modules
  - *Module agents have to manage their own workload in order to avoid congestion*

- At the material to be conveyed
  - *Baggage agents are responsible for their route through the net*
The Internet of Things
State Space of Agent Systems

- Available information
  - Much: global, up-to-date
  - Little: local, out-of-date

- Algorithmic complexity
  - High: Complex computations
  - Low: Simple conditional rules

- Scenarios
  - Topology, dispatching, error handling, etc.

Own space → difficult to formalize
E.g., density of topology network
The Internet of Things
A Simple Scenario

Diagram showing a process with 'Check in', 'Transfer', and 'Sorter' stages.
The Internet of Things
Three Scenarios

For all scenarios: Baggage agents plan their route exactly once, at Check In. Congested edges will be ignored.

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>Baggage agent</th>
<th>Conveyor agent</th>
<th>Communication</th>
</tr>
</thead>
</table>
| Stupid        | Algorithm: Dijkstra  
Required edge information:  
- Lengths of edges | Knowledge about itself:  
- Length | B: What is your length?  
C: $x$ meters |
| Up-to-date    | Algorithm: Dijkstra  
Required edge information:  
- Length of edges  
- Current workload  
($=>$ Penalty cost) | Knowledge about itself:  
- Length  
- Current workload | B: What is your length?  
C: $x$ meters  
B: What is your current workload?  
C: $y$ parcels |
| Anticipatory  | Algorithm: Dijkstra  
Required edge information:  
- Lengths of edges  
- Expected workload at time $t$  
($=>$ Dynamic penalty cost) | Knowledge about itself:  
- Length  
- Expected work load progression | B: What is your length?  
C: $x$ meters  
B: What is your expected workload at time $t_1$?  
C: $y$ parcels  
B: Expect me at time $t_2$!  
C: Well, I will update my forecast. |
The Internet of Things
Stupid Routing – Situation Short After Dispatching

check in
transfer
sorter
sorter
The Internet of Things
Anticipatory Routing – Situation Short After Dispatching
Conclusion

- The rapid increasing complexity of industrial challenges requires usage of mathematical methods of modeling, simulation and optimization to a great extent.
- Mathematicians and computer scientists are invited,
  - To improve available tools and methods continuously, and
  - To assist usage of such methods within projects along the complete life cycle of products, plants and systems.
- The tight, project related collaboration with engineers and users is essential for the successful application of such methods.
Thank you for your attention!

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