



Funded by the
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Introduction and Motivation

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Constraint Based Production Scheduling



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Key Points



- Introducing a running example
- AI is more than LLM
- Stochastic vs. deductive AI methods
- Constraint Based Scheduling and its alternatives
- Key advantages
 - Compositional
 - Reusable
 - Explainable
- Course structure

Outline



A Running Example

Artificial Intelligence

Scheduling

Course Structure

Summary

Developing a Generic Scheduling Tool



- No programming, configured by JSON input data
- Compositional use of different constraint types
- Different commercial or open-source back-end solvers
- Developed in Java
- Interactive JavaFX front-end
- Can be used as back-end scheduling tool/server
- Instance generator included
- Readers for multiple benchmark types included
- Release planned early 2025
- Preview during the course, hands-on experience this afternoon

Introducing a Simple Scheduling Problem



- Will be used throughout the program
- Generated by instance generator
- 50 orders for different products, release and due dates
- 4 stages, always performed in the same sequence
- Two identical machines available for each stage
- Cumulative manpower constraint
- Complete description as JSON document

Excerpt of JSON Description



```
1  "order": [  
2      {  
3          "product": "Prod0",  
4          "process": "Process 0",  
5          "due": 5449,  
6          "releaseDate": "1/10/2024 00:00",  
7          "release": 0,  
8          "qty": 7,  
9          "dueDate": "19/10/2024 22:05",  
10         "name": "Order0",  
11         "earlinessWeight": 1,  
12         "latenessWeight": 1  
13     },
```

Orders Loaded

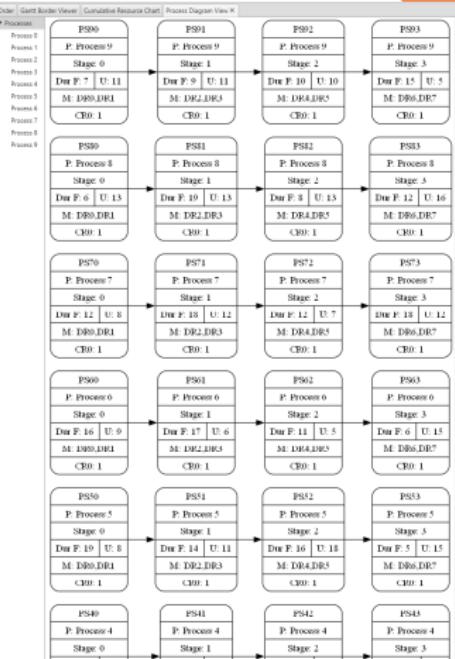


Order X											
Name	Nr	Product	Process	Qty	Due	DueDate	Release	ReleaseDate	LatenessWeight	EarlinessWeight	
Order0	0	Prod0	Process 0	7	5,449	19/10/2024 22:05	0	1/10/2024 00:00	1,0	1,0	
Order1	1	Prod1	Process 1	6	2,134	8/10/2024 09:50	0	1/10/2024 00:00	1,0	1,0	
Order2	2	Prod1	Process 1	7	1,266	5/10/2024 09:30	0	1/10/2024 00:00	1,0	1,0	
Order3	3	Prod1	Process 1	1	1,976	7/10/2024 20:40	0	1/10/2024 00:00	1,0	1,0	
Order4	4	Prod1	Process 9	5	2,866	10/10/2024 22:50	0	1/10/2024 00:00	1,0	1,0	
Order5	5	Prod9	Process 9	3	3,339	12/10/2024 14:15	0	1/10/2024 00:00	1,0	1,0	
Order6	6	Prod4	Process 4	9	1,676	6/10/2024 19:40	0	1/10/2024 00:00	1,0	1,0	
Order7	7	Prod5	Process 5	4	5,471	19/10/2024 23:55	0	1/10/2024 00:00	1,0	1,0	
Order8	8	Prod8	Process 8	1	1,966	7/10/2024 19:50	0	1/10/2024 00:00	1,0	1,0	
Order9	9	Prod8	Process 8	1	4,279	15/10/2024 20:35	0	1/10/2024 00:00	1,0	1,0	
Order10	10	Prod9	Process 9	6	5,733	20/10/2024 21:45	0	1/10/2024 00:00	1,0	1,0	
Order11	11	Prod4	Process 4	4	3,088	11/10/2024 17:20	0	1/10/2024 00:00	1,0	1,0	
Order12	12	Prod8	Process 8	9	2,569	9/10/2024 22:05	0	1/10/2024 00:00	1,0	1,0	
Order13	13	Prod7	Process 7	4	2,331	9/10/2024 02:15	0	1/10/2024 00:00	1,0	1,0	
Order14	14	Prod4	Process 4	9	3,290	12/10/2024 10:10	0	1/10/2024 00:00	1,0	1,0	
Order15	15	Prod3	Process 3	6	1,968	7/10/2024 20:00	0	1/10/2024 00:00	1,0	1,0	
Order16	16	Prod4	Process 4	8	1,579	6/10/2024 11:35	0	1/10/2024 00:00	1,0	1,0	
Order17	17	Prod1	Process 1	3	4,263	15/10/2024 19:15	0	1/10/2024 00:00	1,0	1,0	
Order18	18	Prod5	Process 5	9	4,491	16/10/2024 14:15	0	1/10/2024 00:00	1,0	1,0	
Order19	19	Prod1	Process 3	4	613	3/10/2024 03:05	0	1/10/2024 00:00	1,0	1,0	
Order20	20	Prod6	Process 6	2	5,034	18/10/2024 11:30	0	1/10/2024 00:00	1,0	1,0	
Order21	21	Prod7	Process 7	4	1,797	7/10/2024 05:45	0	1/10/2024 00:00	1,0	1,0	
Order22	22	Prod8	Process 8	7	4,286	15/10/2024 21:10	0	1/10/2024 00:00	1,0	1,0	
Order23	23	Prod9	Process 9	8	1,970	7/10/2024 20:10	0	1/10/2024 00:00	1,0	1,0	
Order24	24	Prod3	Process 3	4	1,266	5/10/2024 11:10	0	1/10/2024 00:00	1,0	1,0	
Order25	25	Prod1	Process 6	6	4,170	15/10/2024 11:30	0	1/10/2024 00:00	1,0	1,0	
Order26	26	Prod8	Process 8	4	5,481	20/10/2024 00:45	0	1/10/2024 00:00	1,0	1,0	
Order27	27	Prod1	Process 1	4	3,255	12/10/2024 07:15	0	1/10/2024 00:00	1,0	1,0	
Order28	28	Prod3	Process 3	7	1,021	4/10/2024 13:05	0	1/10/2024 00:00	1,0	1,0	
Order29	29	Prod5	Process 5	4	5,315	19/10/2024 10:55	0	1/10/2024 00:00	1,0	1,0	
Order30	30	Prod9	Process 9	7	5,075	18/10/2024 14:55	0	1/10/2024 00:00	1,0	1,0	
Order31	31	Prod1	Process 1	6	3,089	11/10/2024 17:25	0	1/10/2024 00:00	1,0	1,0	
Order32	32	Prod0	Process 0	8	3,324	12/10/2024 13:00	0	1/10/2024 00:00	1,0	1,0	
Order33	33	Prod7	Process 7	9	607	3/10/2024 02:35	0	1/10/2024 00:00	1,0	1,0	
Order34	34	Prod9	Process 9	1	2,914	11/10/2024 02:50	0	1/10/2024 00:00	1,0	1,0	

Process Diagram



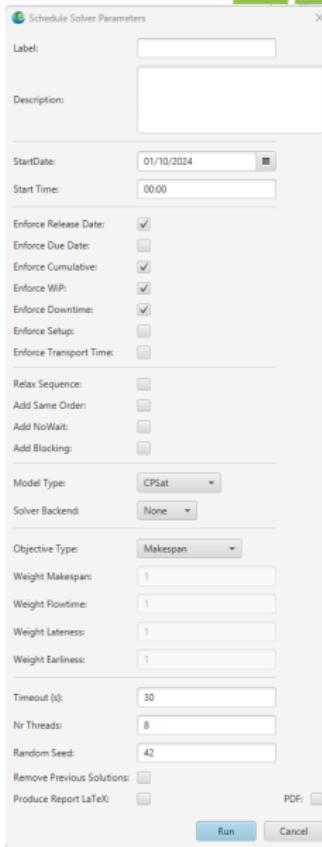
- Processes describe how products are made
- Multiple process steps
- Not always in a straight sequence
- Duration formula based on quantity made
- Temporal constraints between steps
- Possible machines to run on
- Resource requirements (manpower, electricity,...)



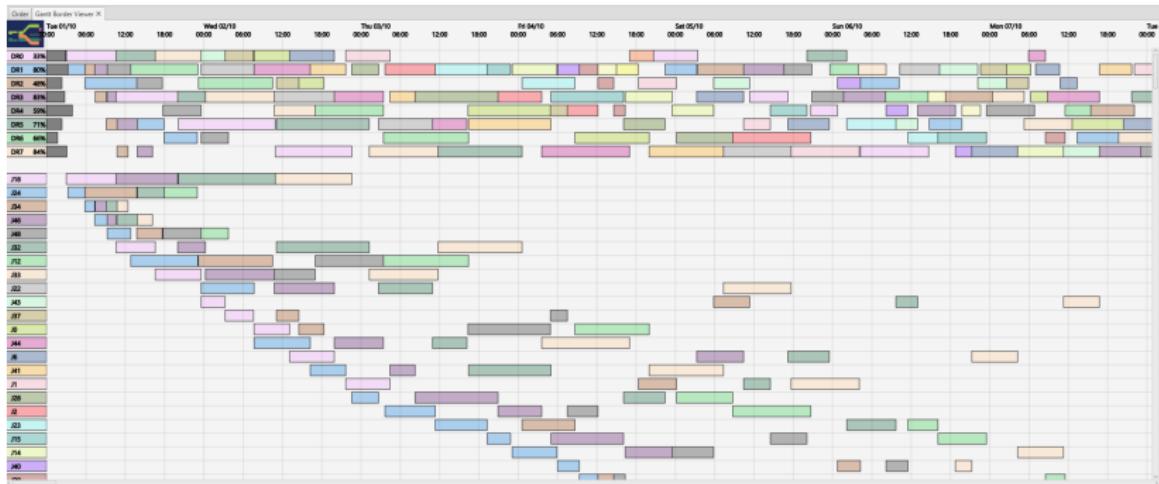
Selecting Solver Options



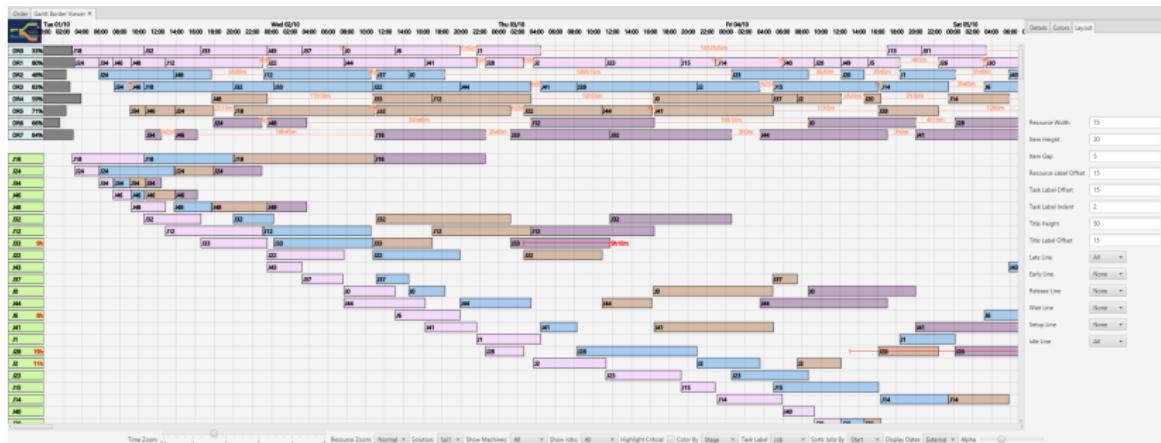
- Which constraints to enforce
 - Here: do not enforce due dates
- Additional constraints to try
- Why solver to run
 - Here: Use open-source CPSat solver
- Which objective to use
 - Here: Makespan, overall project end
- What resources to use
 - Allow 30 seconds
 - Use 8 parallel threads



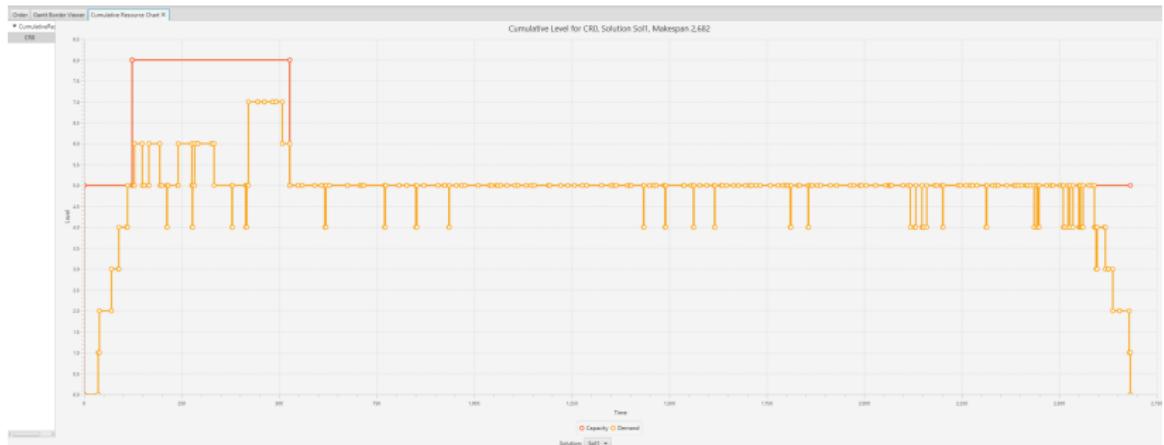
Schedule - Initial Gantt Chart



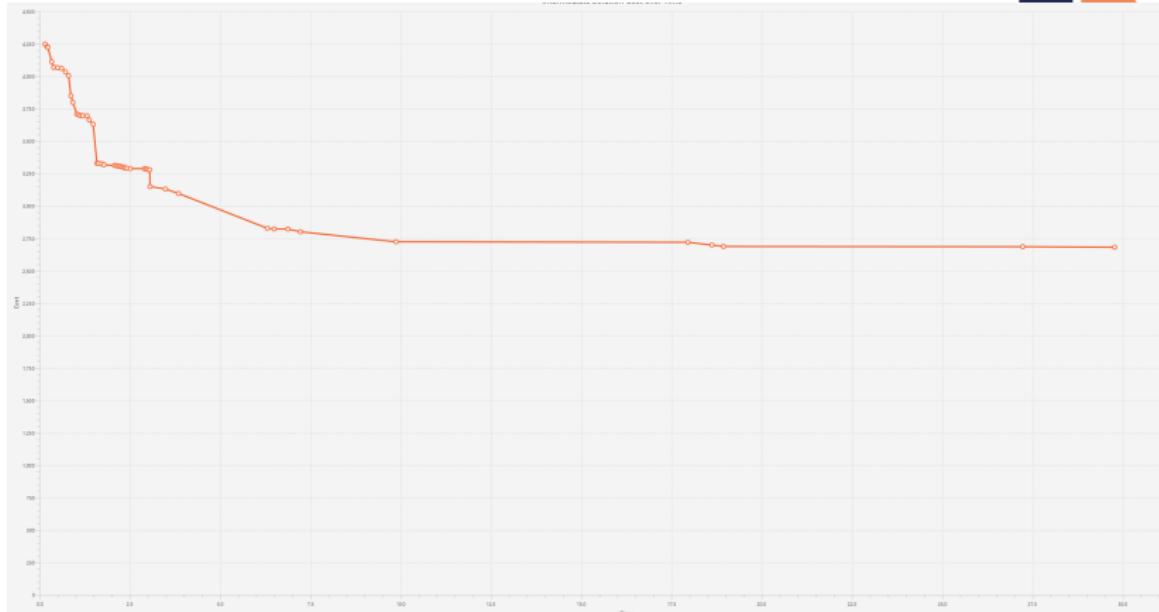
Adapted Gantt Chart



Cumulative Resource Chart



Intermediate Solutions Found



- Ongoing search for improved solutions
- Depends on time and resources, solver used

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Constraint-Based Scheduling

Other Scheduling Solution Approaches

Course Structure

Summary

Constraint Programming - in a nutshell



- Declarative description of problems with
 - *Variables* which range over (finite) sets of values
 - *Constraints* over subsets of variables which restrict possible value combinations
 - A *solution* is a value assignment which satisfies all constraints
- Constraint propagation/reasoning
 - Removing inconsistent values for variables
 - Detect failure if constraint can not be satisfied
 - Interaction of constraints via shared variables
 - Incomplete
- Search
 - User controlled assignment of values to variables
 - Each step triggers constraint propagation
- Different domains require/allow different methods

Constraint Programming is Different



- Declarative Programming
 - Concentrate on what you want
 - Not how to get there
 - Program != Algorithm
 - Program = Model
- Applied to Combinatorial Problems
 - No complete polynomial algorithms known (exist?)
 - CP less ad-hoc than heuristics
 - Models can evolve

A Subtractive Process



“Oh, bosh, as Mr. Ruskin says. Sculpture, per se, is the simplest thing in the world. All you have to do is to take a big chunk of marble and a hammer and chisel, make up your mind what you are about to create and chip off all the marble you don’t want.” -Paris Gaulois.

Source: <https://quoteinvestigator.com/2014/06/22/chip-away/>

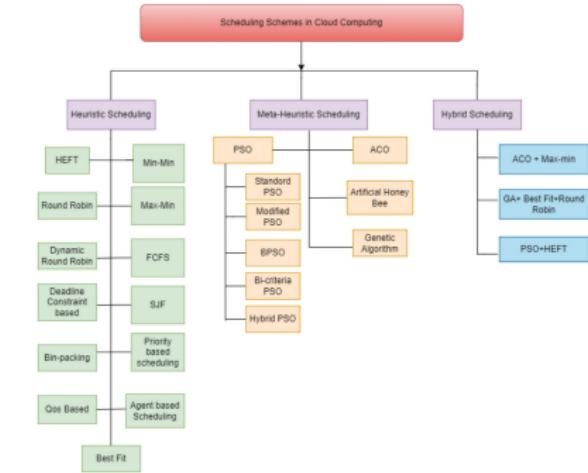
Other Technologies



- Heuristics
- Integer Programming
- Local search
- Deep neural networks

Heuristics

- Do not try to explore the search space
- Find a good enough solution by making greedy choices
- More general meta-heuristics schemes
- Very good heuristics exist for specific problem types
- Not compositional, added constraints may destroy existing approach
- Often not reusable code base

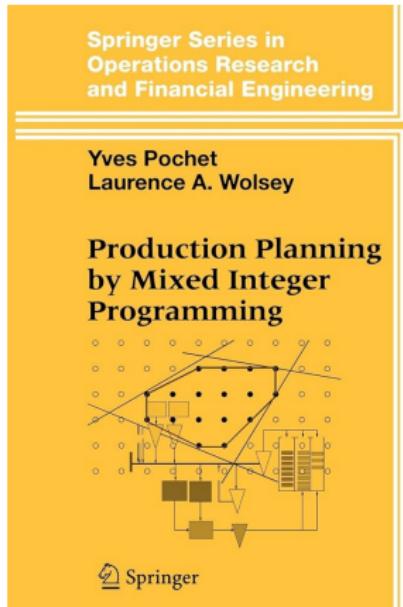


From: Singh, Kumar, and Singh: An empirical investigation of task scheduling and VM consolidation schemes in cloud environment, Computer Science review, 2023, <https://www.sciencedirect.com/science/article/pii/S1574013723000503>

Integer Programming



- Sub-class of constraint programming
- Restrict yourself to linear constraints
- Powerful reasoning on the complete set of constraints
 - Linear Programming
 - Cut generation
- Expressing scheduling constraints can be difficult
- Scalability issues



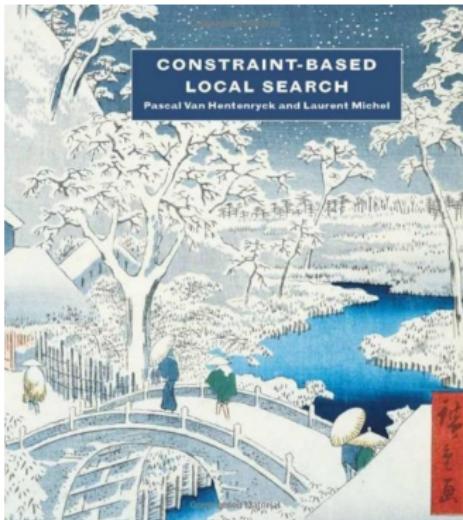
<https://link.springer.com/book/10.1007/0-387-33477-7>

0-387-33477-7

Local Search



- Start with an initial solution
- Try out changes that maintain feasibility
- Gradual improvement over time
- Not compositional
- No guarantee of solution quality
- Unifying approach:
Constraint-Based Local
Search



[https://mitpress.mit.edu/9780262220774/
constraint-based-local-search/](https://mitpress.mit.edu/9780262220774/constraint-based-local-search/)

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What is not covered?

Summary

Course Structure



Time	Day 1	Day 2
09:00-10:30	Introduction & Motivation	Costs & Objective Functions
10:30-11:00	Coffee	Coffee
11:00-12:30	Scheduling Concepts	Advanced Concepts
12:30-14:00	Lunch	Lunch
14:00-15:30	Machine Constraints	Case Studies
15:30-16:00	Coffee	Coffee & Close
16:00-17:00	Experiments	-

What is not covered?



- How does it all work?
- How to integrate into an existing IT environment
- How to define and solve new constraints
- Interactive solving techniques

How does it all work?



- You don't really need to know this to use Constraint Programming
- Advantage of declarative, compositional formulation
- I teach an introductory course on Constraint Programming for CRT-AI
- Overview of courses, books and materials at
<https://arxiv.org/abs/2403.12717>

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Summary

Summary



- Why use Constraint Based Scheduling?
- Compared to other AI methods
- Compared to other solution approaches