Dynamic Scheduling

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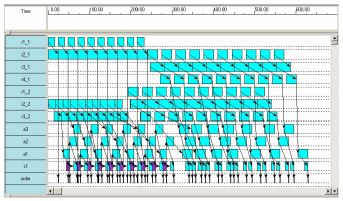
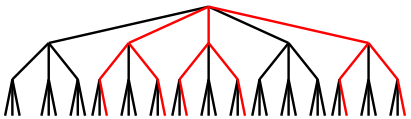
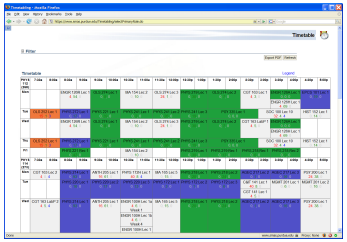
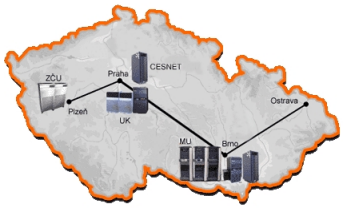
Dynamic scheduling

1. Problem description
2. Solving methods
   - Dispatching rules and policies
   - Local search
   - Branch & bound
   - Iterative forward search
3. Applications
   - Scheduling in Grid environment
   - University course timetabling





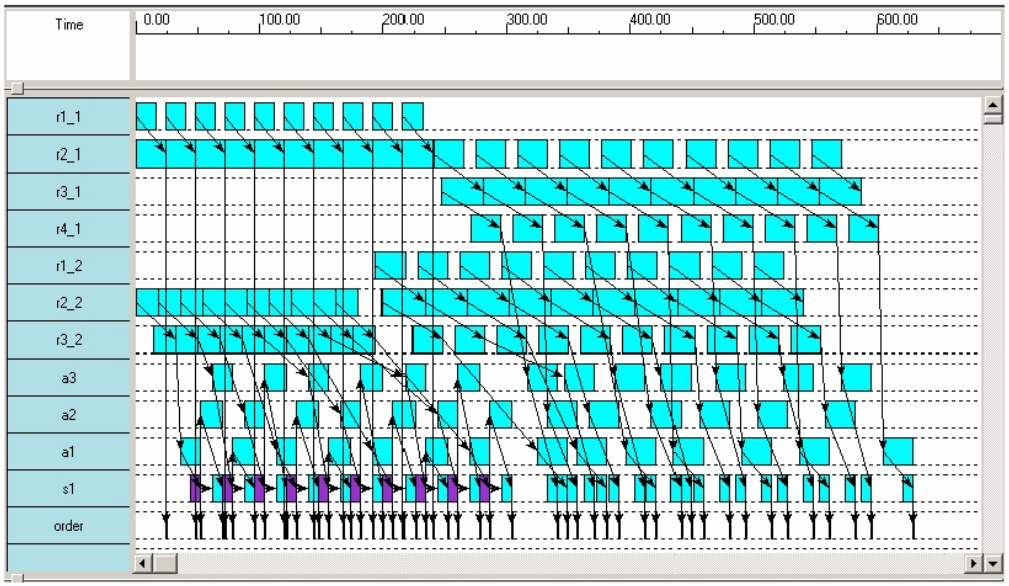




Static scheduling

Scheduling

- resources/machines vs. activities/jobs
- optimal resource allocation of activities over the time



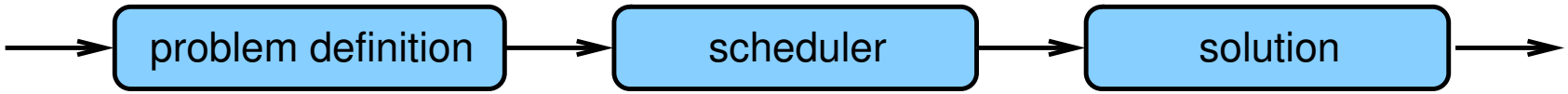
Visopt ShopFloor System

Classical scheduling = static scheduling

- all resources and all activities are given
- no uncertainty in the behavior of resources and activities

Dynamic scheduling

- Problem change during the solving process
- Examples:
  - unscheduled resource breakdown
  - new jobs appear during solving phase
  - shorter/longer processing time than expected



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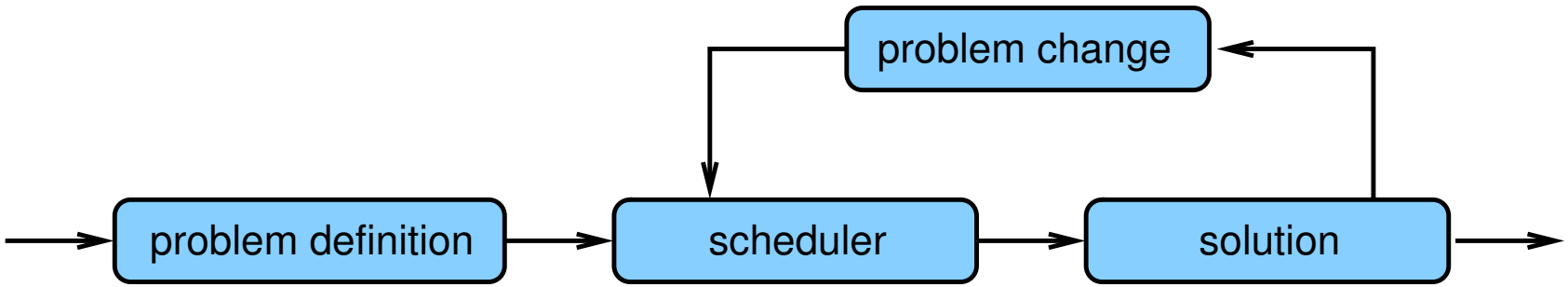

Minimal perturbation problem

- New solution with minimal changes/perturbation from original solution
  - solution published
  - changes undesirable wrt. user
  - try to avoid avalanche effect
- Examples: school timetable, flight assignment, ...

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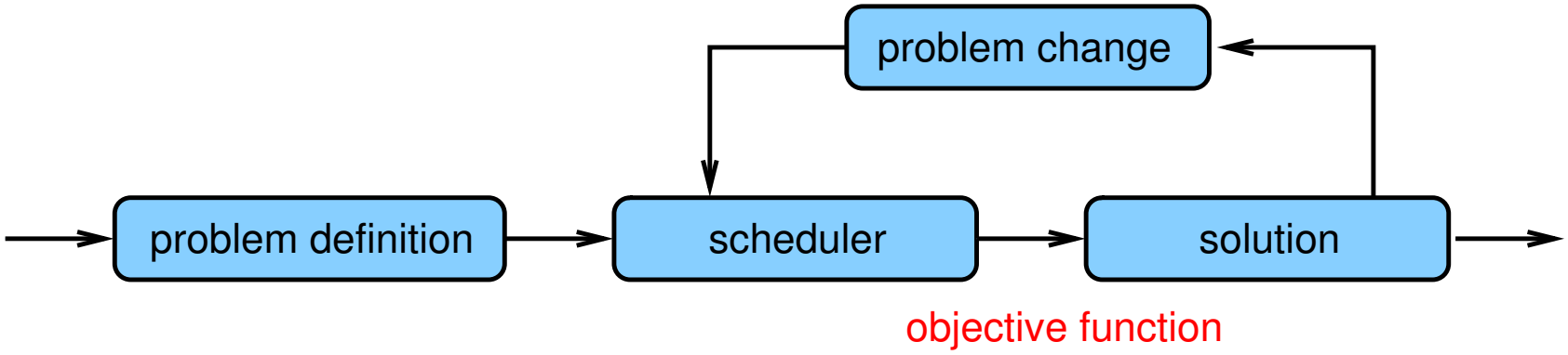
- Examples: school timetable, flight assignment, ...
- Minimal perturbation problem: $(P, \alpha, C^+, C^-, \delta)$
  - P is a problem
  - α solution of P
  - C^+, C^- sets of new and removed constraints
  - δ distance function over two solutions
- Solution of minimal perturbation problem
  - solution β of the problem with $C \backslash C^- \cup C^+$ with minimal distance $\delta(\beta, \alpha)$

Solving: dynamic problem vs. minimal perturbation problem

Dynamic problem



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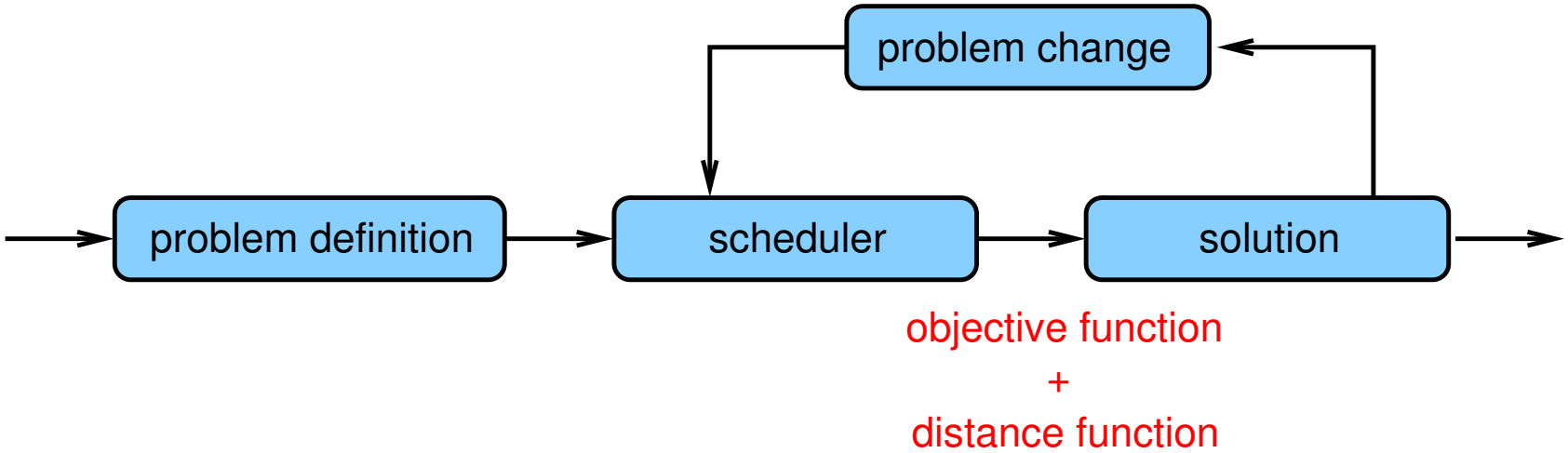
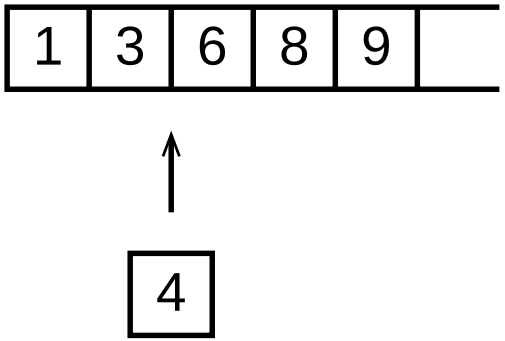


Dispatching rules and policies

Dispatching rules (static problems)

- new job assigned to the resource wrt. rule
- rule = longest job/job with smallest due date/... earlier
- combination of several rules



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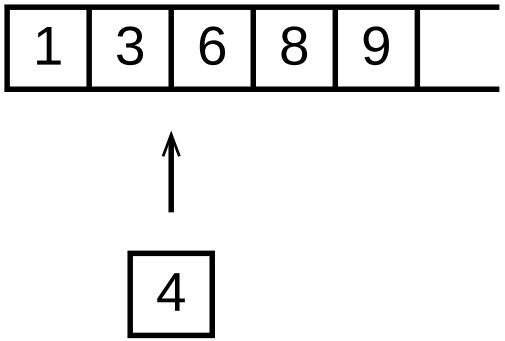


Policies (dynamic problems)

- again: new job assigned to the resource wrt. policy
- dynamics: new information concerning jobs and machines becomes available continuously

Dispatching rules and policies

Optimal for specific problems

- Earliest Due Date (EDD) first rule optimal for $1||L_{\max}$

Good for problems

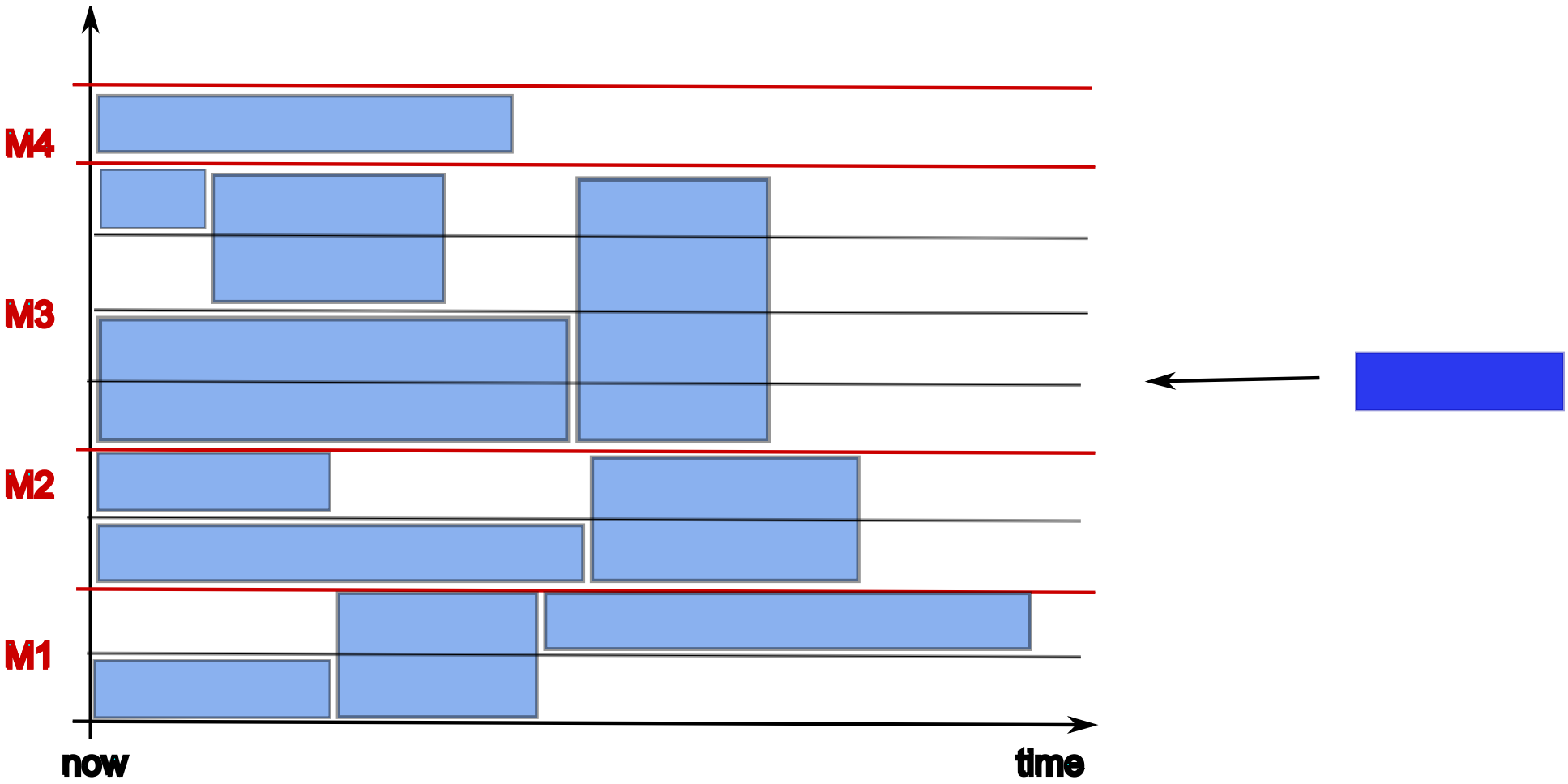
- high dynamics
  - subsequently appearing jobs
  - uncertain processing time
  - resource breakdowns
- the need for a prompt response

Not helpful for (complex) optimization

- minimal perturbation problem
- Quality of Service (QoS) requirements

Complex policy

Place jobs to the Earliest Gap in a machine where it fits



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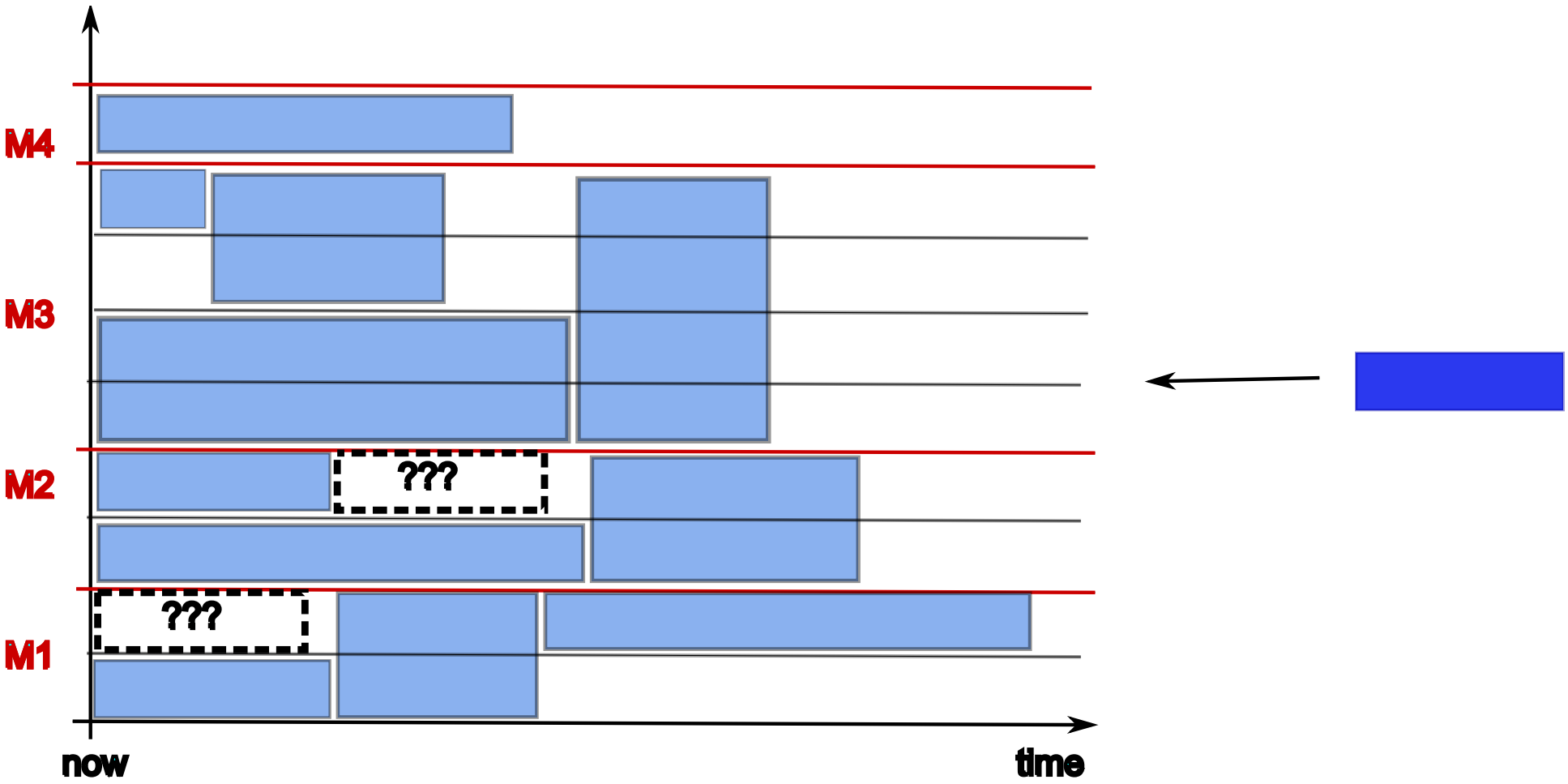
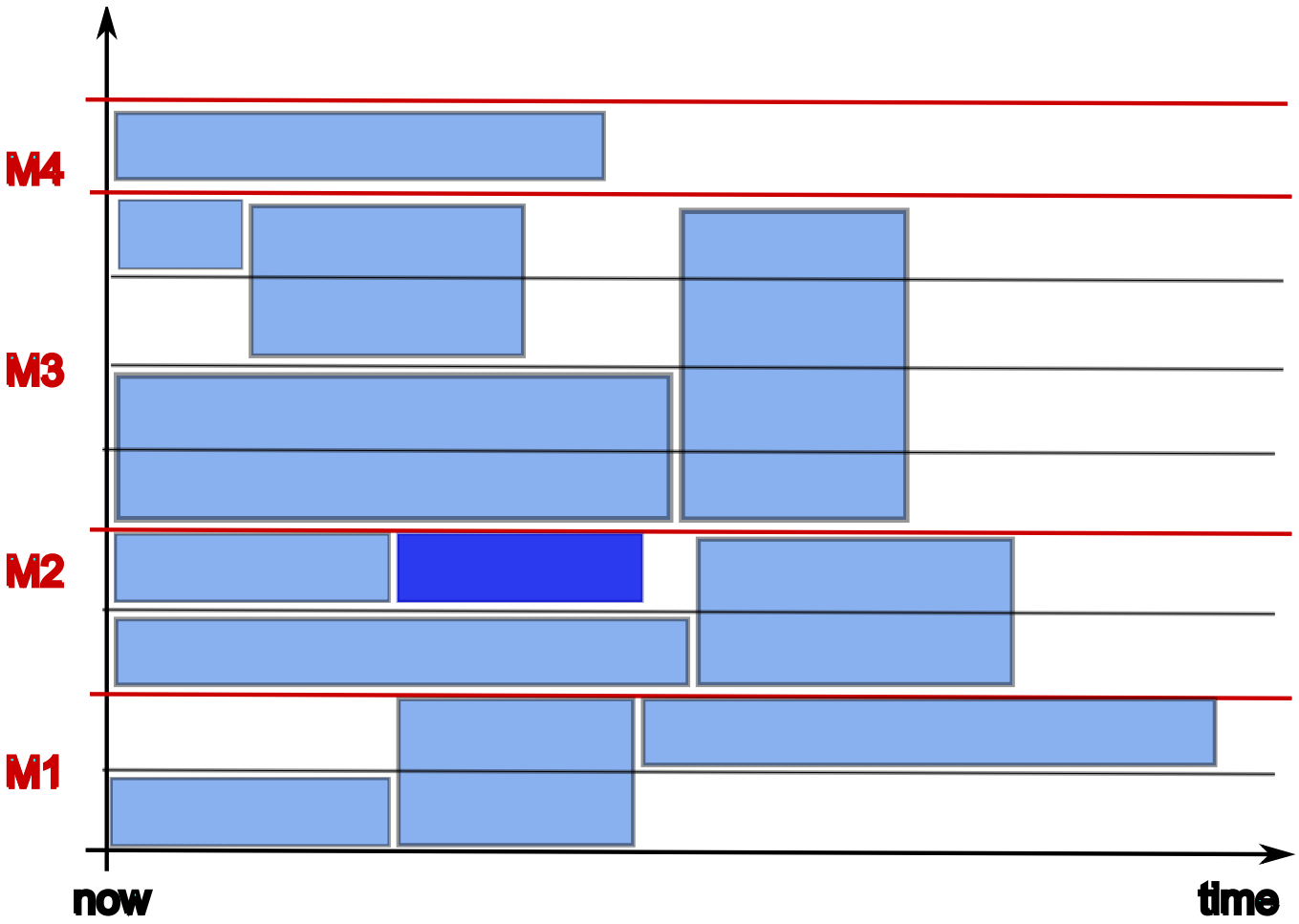


Complex policy

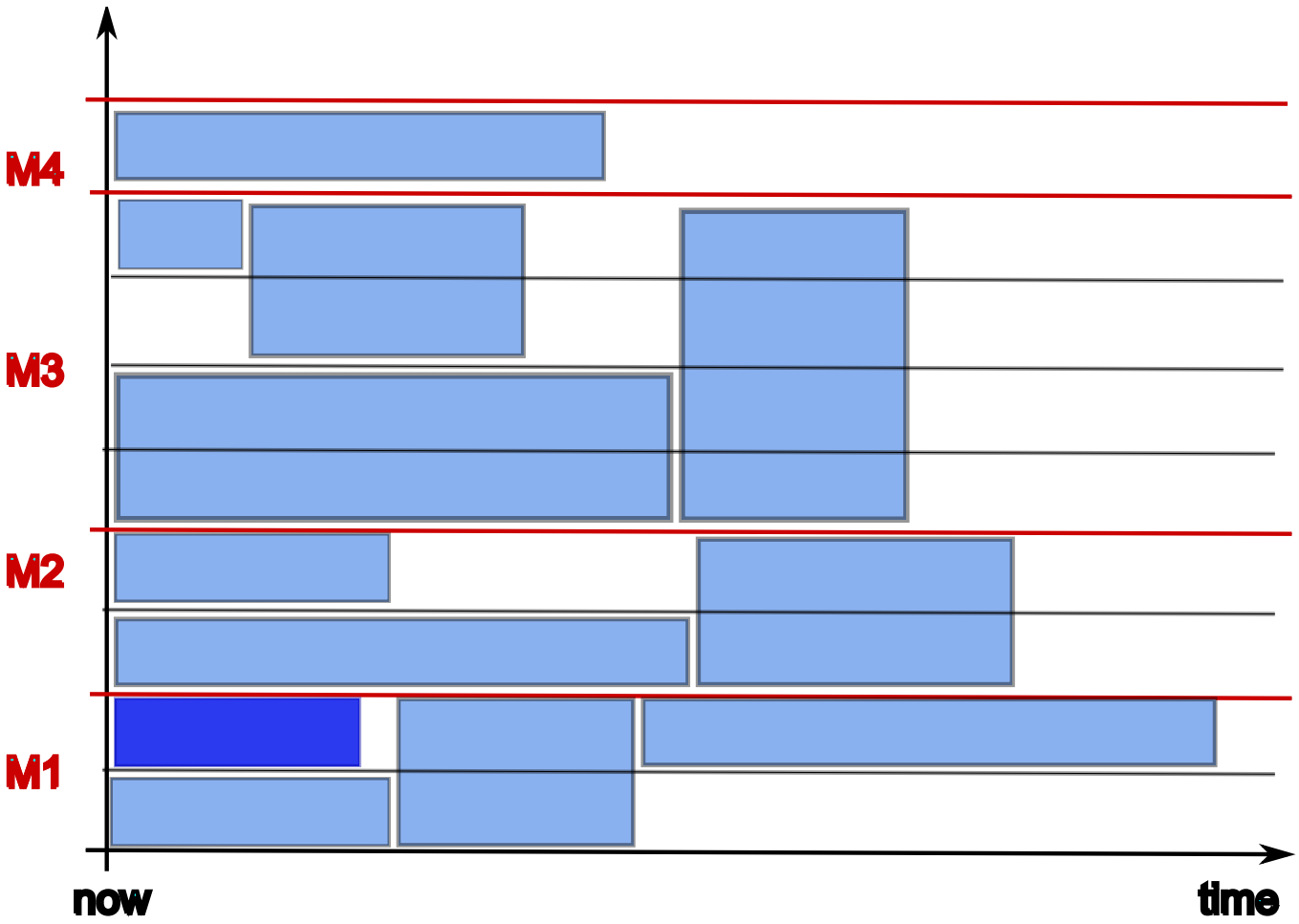
Place jobs to the Earliest Gap in a random machine where it fits



Random Earliest Gap

Complex policy

Place jobs to the Earliest Gap in the best machine where it fits



Best Earliest Gap

Local search (LS) in scheduling

- Initial schedule: complete, random generation (trivially)
  - example: 10 jobs on one machine

1	3	6	8	7	10	9	2	4	5

- Local changes/repairs of complete inconsistent schedule
  - exchange of two jobs,
    job moved to different resource, ...

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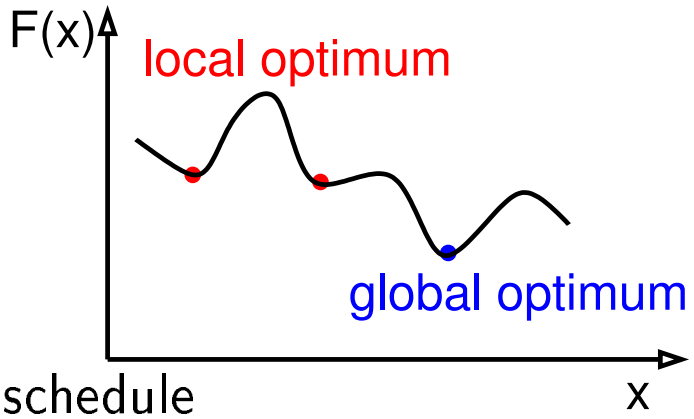
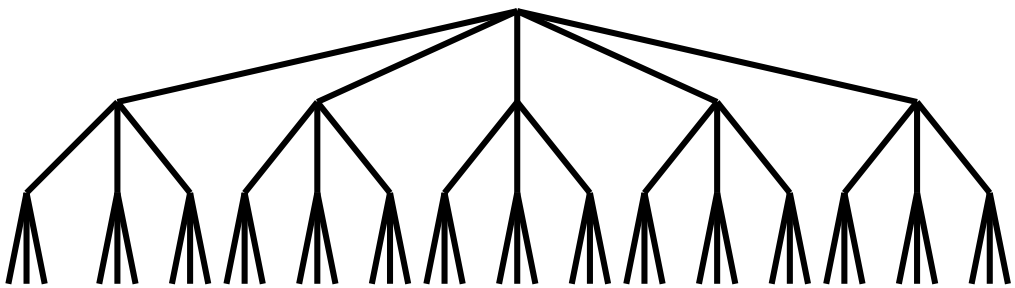


- Static scheduling: search goals
  1. improvements in objective function
  2. search for consistent schedule
- Dynamic scheduling: extension
  3. solution of original problem as initial schedule
  4. natural extension
  5. good time complexity
- Minimal perturbation problem: extension
  6. minimization of the different values (e.g. job assignments)
  7. no optimality guarantees

Tree search

- Constructive search method
  - e.g., subsequent placement of particular activities to schedule
- Search by trivial enumeration



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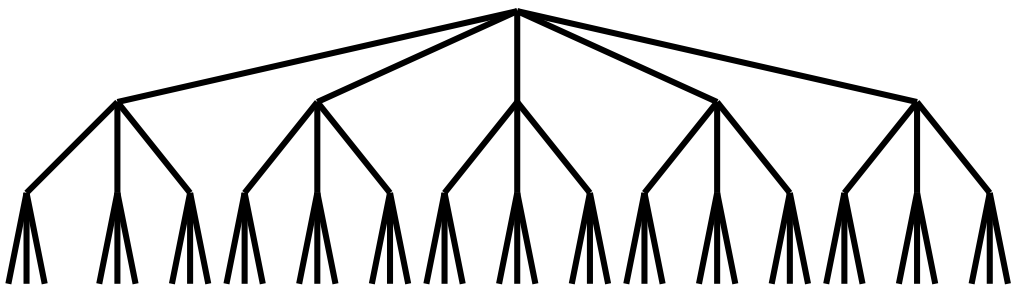
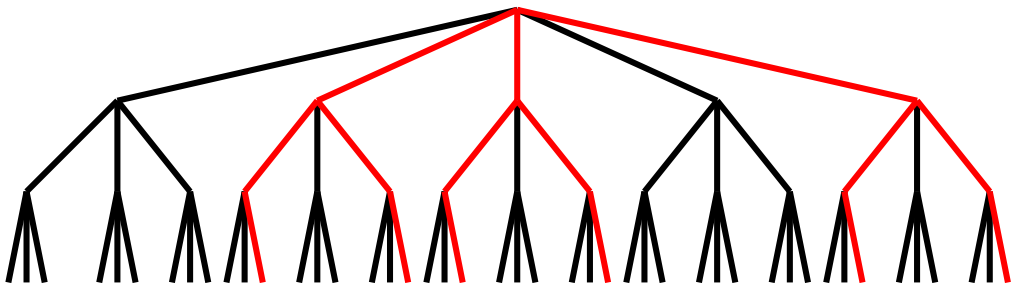


- Constraint propagation
  - propagation =
    inconsistent states and their successors not explored



Branch & bound (BB)

Branch & bound search

- tree search method
- search for optimal solution
- maintained lower bound
- space with quality worse than lower bound pruned

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Local search

- large scale problems
- no guarantee of solution quality

Branch & bound

- not applicable for large scale problems
- can be used for local optimization

BB: dynamic scheduling

We have: solution of original problem + new changes

and want "improve it"

Selection of activity x with improper placement

Application of BB with at most n changes

- reasonable n is rather small
- reasonable search space size
- optimality guarantee within this search space
- solution out of this space not reasonable wrt. x anyway

Iterative forward search (IFS) for scheduling

- Constructive method
- Partial consistent schedules

- Standard forward step
  - selection of activities and their placements if possible
- "Backward step"
  1. if impossible to assign selected activities without constraint violation
  2. finding conflicting activities and removal of their placement
  3. assignment of selected activities

Timetable

PHYS 112 (268)	7:30a	8:00a	8:30a	9:00a
Mon			ENGR 126R Lec 1 4, 54, 0	
Tue	OLS 252 Lec 1 15, 1, 3		PHYS 272 Lec 1 0, 17, 0	
Wed			ENGR 126R Lec 1 4, 54, 0	

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- Consequence
  - principles of the local search (local changes)
  - IFS is not a tree search method
- Important principle
  - placement selection
  - conflict statistics (memory for the number of conflicts)

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Conflict statistics

- Suppose: selection of placement a of activity A
  we must remove placement of b for activity B, i.e.

$$[A = a \rightarrow \neg\, B = b]$$

- We can remember during computation

$$A = a \quad \Rightarrow \quad \begin{array}{ll} 3 \times \neg\, B = b, & 4 \times \neg\, B = c \\ 2 \times \neg\, C = a, & 120 \times \neg\, D = d \end{array}$$

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- Placement selection
  - selection of placements with smallest conflicts

IFS for dynamic scheduling

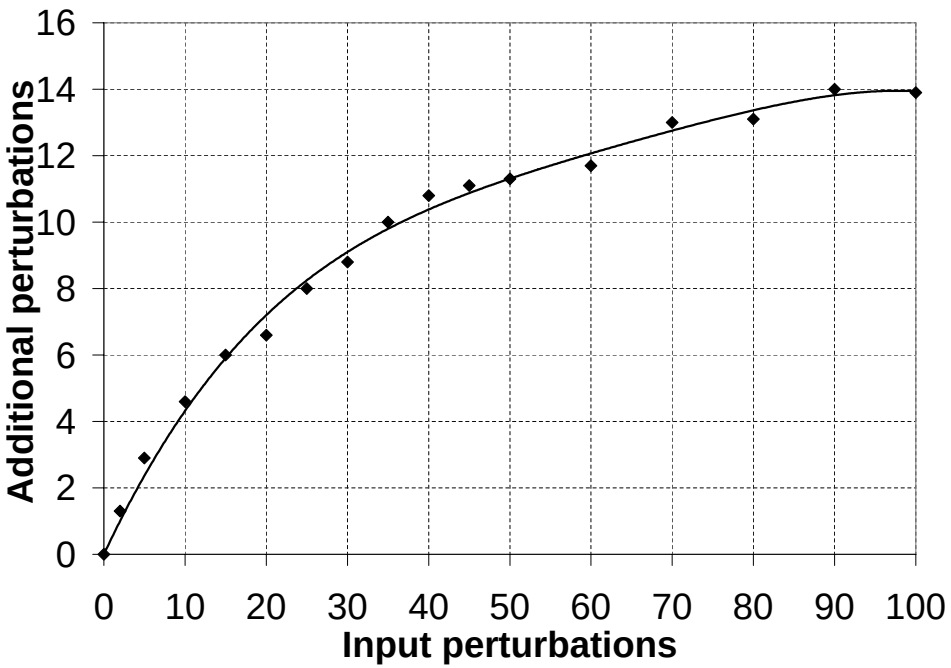
Static scheduling: search goals

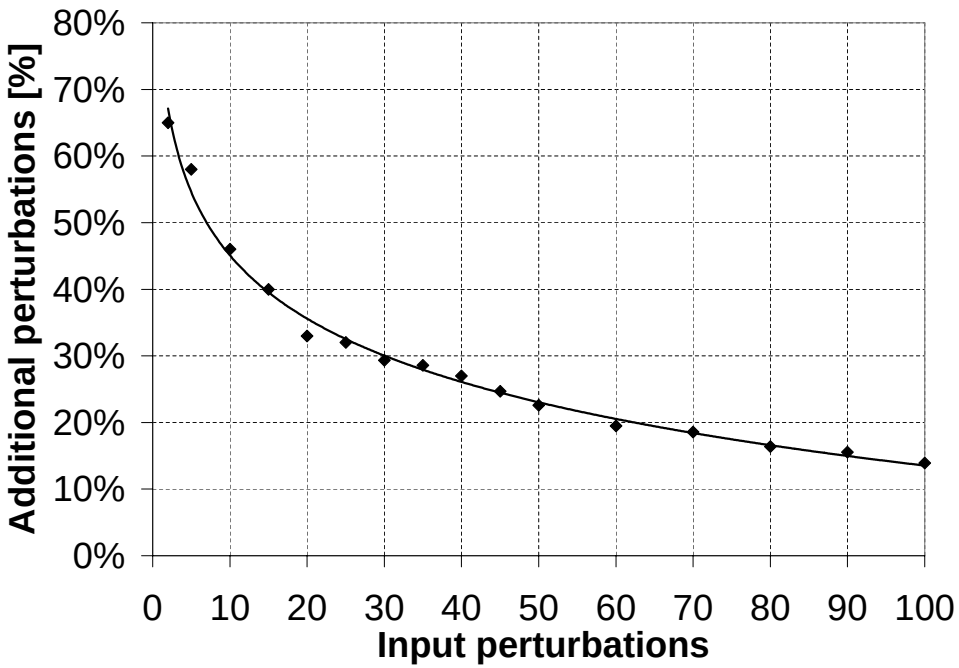
1. search for placement of all activities
2. optimization of the objective function
   - preferred time assignment, preferred resource allocation, ...

Minimal perturbation problem: extension

3. minimization of the number of different placements
4. original placements preferred
   - during placement selection supported
     minimal difference in the number
     of differently assigned activities

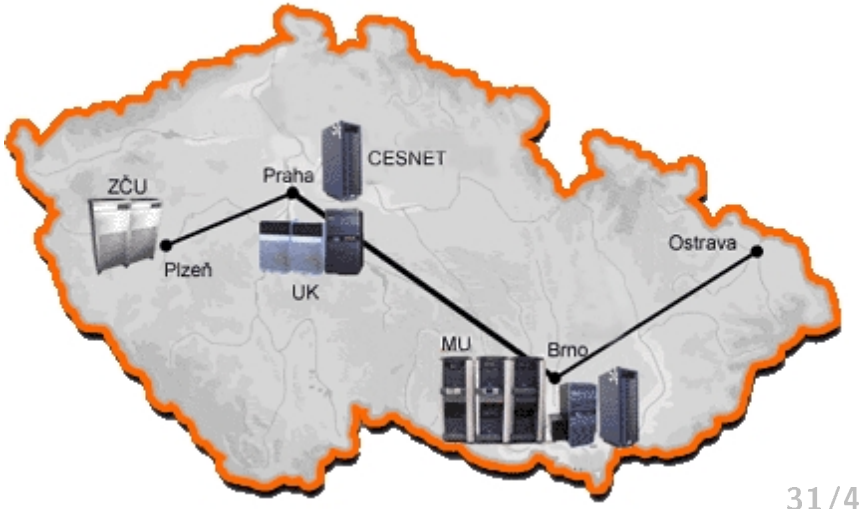
IFS: experiments





Job Scheduling in Grid environment

- Distributed heterogeneous resources
  - clusters, supercomputers, desktops, special instruments
  - autonomy, robustness
- Type of jobs
  - high-throughput (parameter studies), parallel, distributed
- Scheduling on Grids
  - scheduling of computational jobs to resources
  - scheduling of data transfers and data processing
- Examples
  - several clusters over Czech Republic ($\mathcal{META}$ *Center*)
    hundreds clusters over Europe (EGEE)
  - several supercomputers(Deisa)
  - SETI@Home



Grid scheduling with Alea simulator

Problems with QoS requirements

- synthetic problems proposed by the group at ISTI CNR (Italy)
- heterogenous resources (frequency, number of processors)
- dynamic problems
  - jobs arriving over the time
  - known job processing time
  - no resource changes
- deadlines, sw licenses
- resource usage, job slowdown

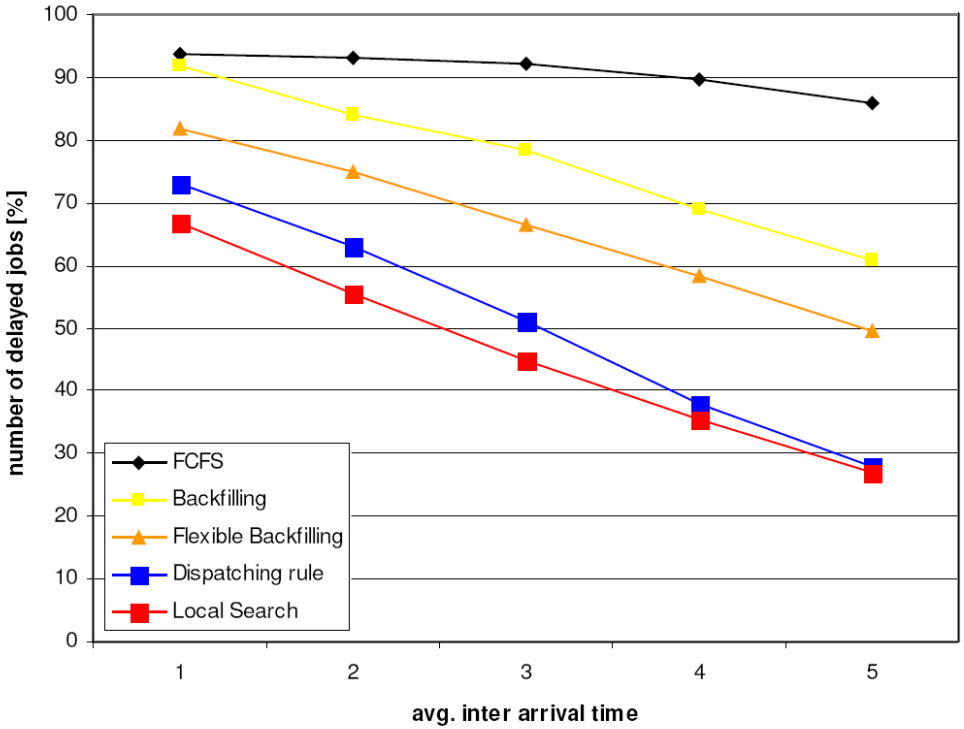
Grid simulator Alea

- extension of simulation tool GridSim (Java)
- centralized scheduler
- modular system: different problems and algorithms
- static and dynamic scheduling
- `http://www.fi.muni.cz/~klusacek/alea`

Local search for dynamic grid scheduling

- Policies
  - common use in the theory and practice
  - used for generation of the initial solution
- Local search
  - applied to static grid scheduling problems - very slow
    grid community very sceptical to
    the effective use of local search!
  - local search not yet applied to the dynamic grid scheduling
    - computation of the schedule from scratch too slow
- Goal
  - application of local search to dynamic grid scheduling problems
  - generally
    - parallel jobs, QoS, interactive jobs, advance reservation, ...
    - application of advanced AI/OR algorithms
- Current results
  - synthetic problems with QoS requirements
  - improvements in optimization results, very good running time

Local search: experiments (deadlines vs. machine usage)



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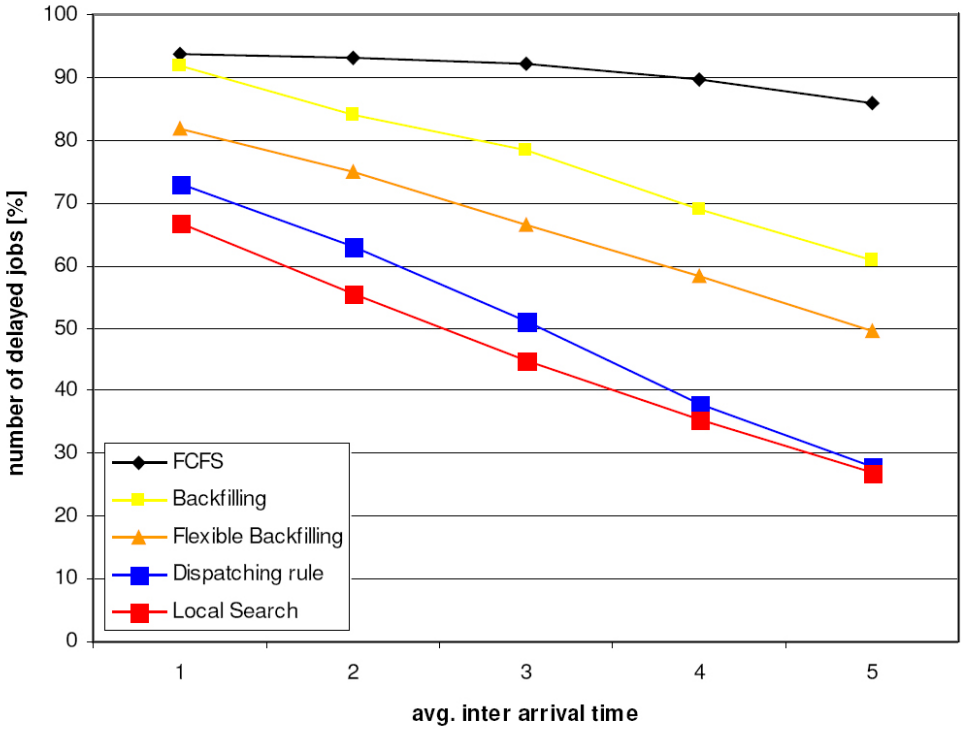
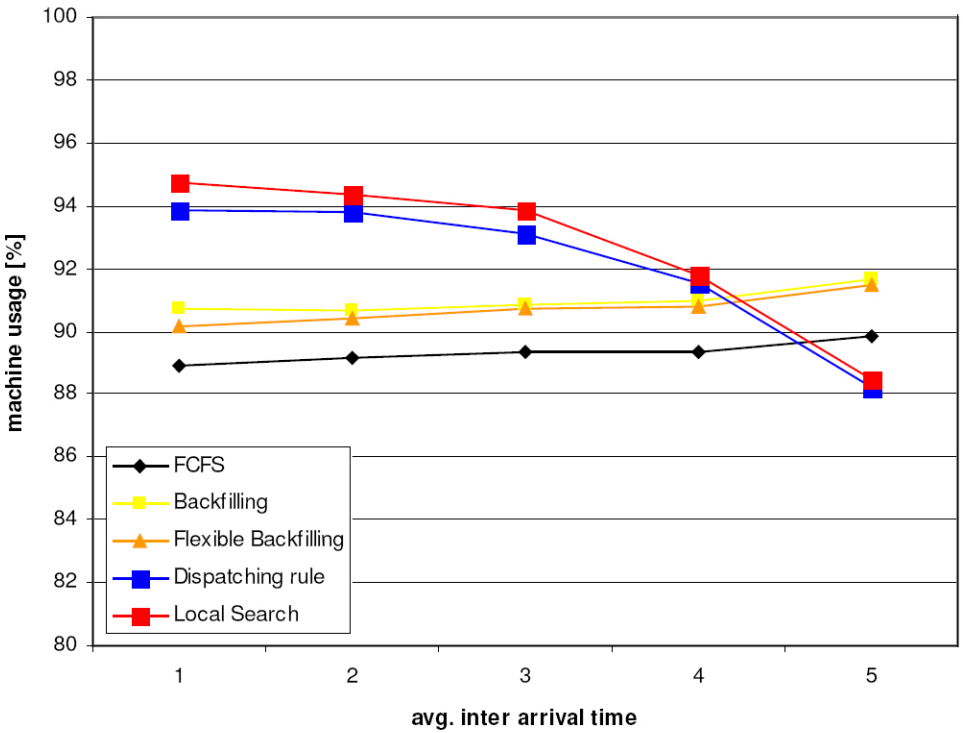
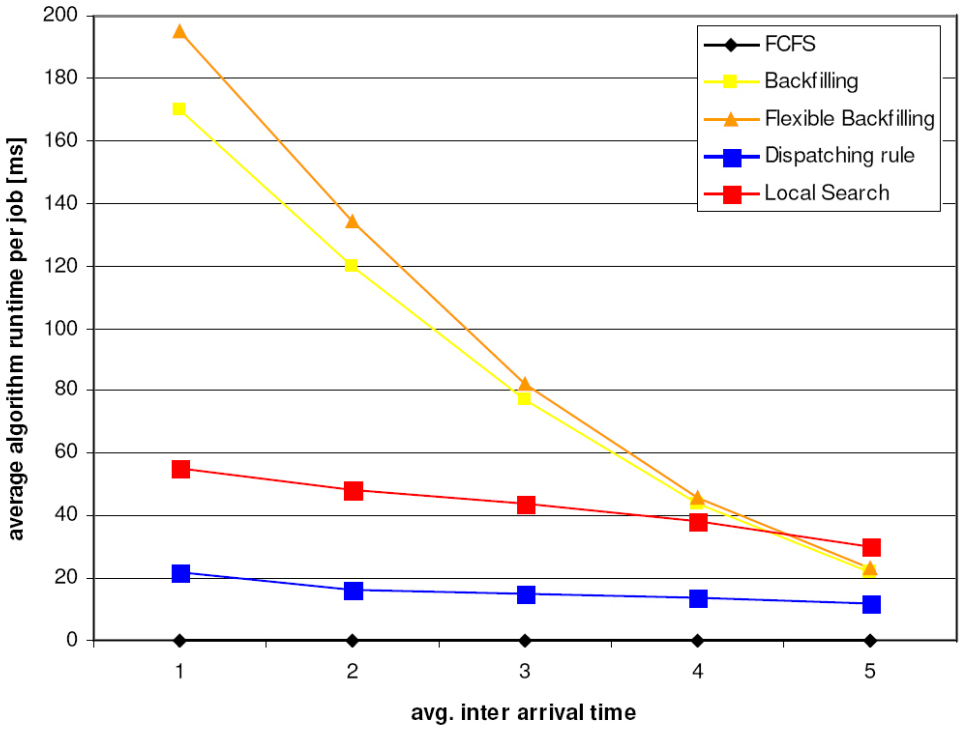
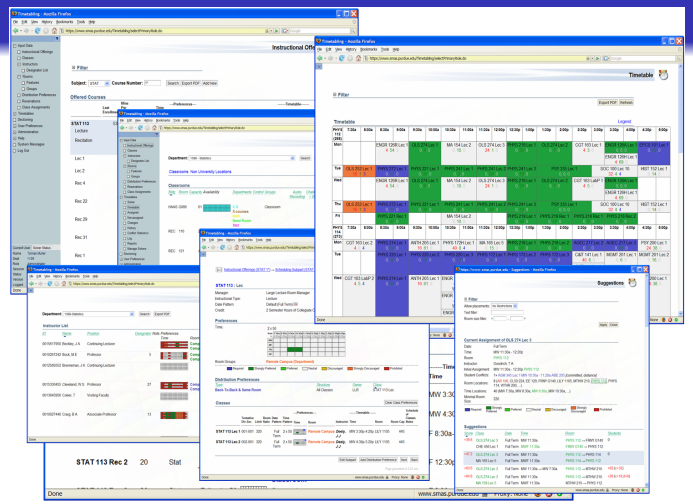




Local search: experiments (run-time)



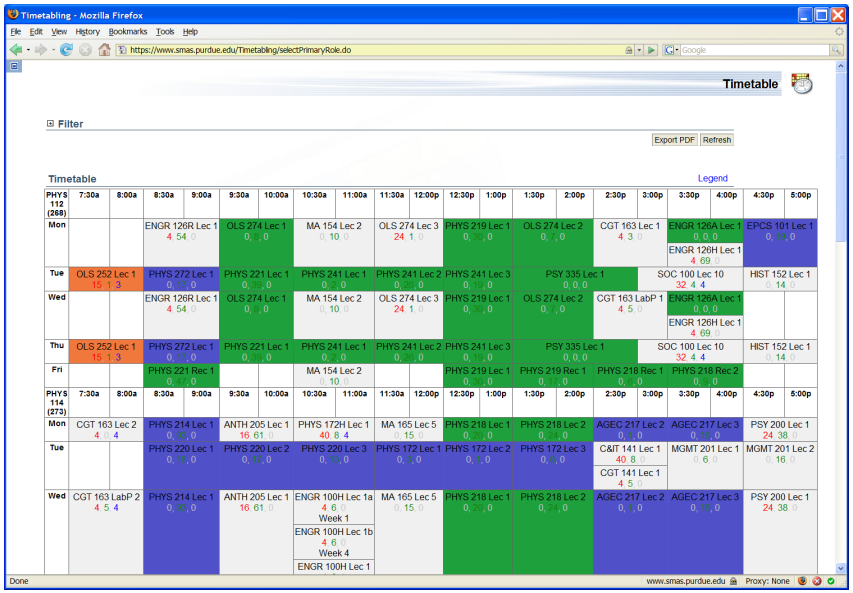
University course timetabling



- Timetabling at Purdue University
  - http://www.unitime.org
- Large scale decentralized problem
  - 2 central problems: large lecture rooms, computer laboratories
  - about 70 problems for particular administrative domains
- State of the project
  - 2001-2005: 3 projects between Masaryk and Purdue University
  - spring 2005: first used large lecture room timetabling
  - autumn 2007: first used system for the whole university
- Timetabling steps
  1. centralized solving of large lecture rooms
  2. solving of particular departmental problems
  3. centralized solving of computer laboratories problem
  4. centralized changes in the timetable

Static timetabling problems

- Large lecture room problem
  - 800 courses x 2 meetings, 55 classrooms
  - individual course enrollment for about 28.000 students
  - preferences on time and space, distances between classrooms,...
  - many exception handled
- Other problems: both automated solving and data input
- Algorithm: Iterative forward search



Minimal perturbation problem

Solving methods

- Iterative forward search to react on user requests
- Branch and bound for local schedule optimization

Suggestions

Score	Class	Date	Time	Room	Students
+15.2	POL 101 Lec 3	Full Term	TTh 12:00p → TTh 7:30a	BRNG 2280	+11
+31.7	POL 101 Lec 3	Full Term	TTh 12:00p → TTh 10:30a	BRNG 2280	+36 (h+3)
	HIST 342 Lec 1	Full Term	TTh 10:30a → TTh 1:30p	BRNG 2280 → BRNG 2290	
+36.6	POL 101 Lec 3	Full Term	TTh 12:00p → TTh 10:30a	BRNG 2280	+36 (h+4)
	HIST 342 Lec 1	Full Term	TTh 10:30a → TTh 7:30a	BRNG 2280	
+44.1	POL 101 Lec 3	Full Term	TTh 12:00p → TTh 10:30a	BRNG 2280	+34 (h+2)
	HIST 342 Lec 1	Full Term	TTh 10:30a → TTh 3:00p	BRNG 2280 → BRNG 2290	
	OBHR 330 Lec 4	Full Term	TTh 3:00p	BRNG 2290 → LWSN B155	

(all 1571 possibilities up to 3 changes were considered, top 4 of 17 suggestions displayed)

Search Deeper

Summary

Search algorithms for scheduling problems

Educational timetabling

- constraint satisfaction
- soft constraints
- local search methods

Grid scheduling

- intelligent scheduling algorithms
- simulators

http://www.fi.muni.cz/~hanka/publ/pisa08.pdf

Successor of Purdue solver

- written by Tomáš Müller
- extension of iterative forward search by local search methods
- International Timetabling Competition 2007
  - finalist in all three tracks, winner of two tracks