A Challenge for an Efficient Supply Chain Management

- Integration versus Optimality -

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Once upon a time …

The origin of my interest for the SCM …

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

UNIVERSITAS · FRIBURGENSIS · HELVETIORUM

FRIUP
SUPPORT PME KMU START-UP

- ***Support SME***
- Improve the production system
- Improve the information system

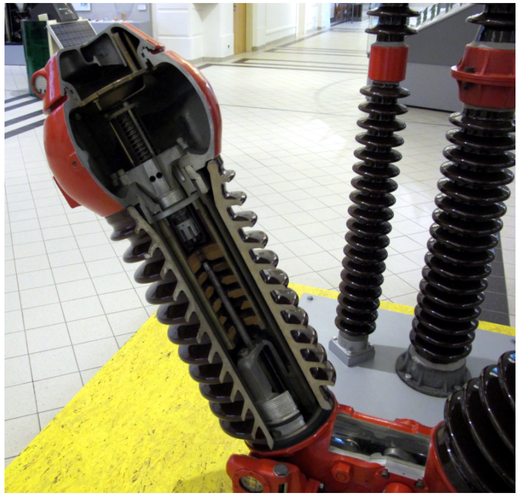
An industrial project

Visit of a production manager

➠ several problems to solve

- two production sites
- manufacture a new product
- limited production resources
- work-in-progress inventories
- introduction of a pull system

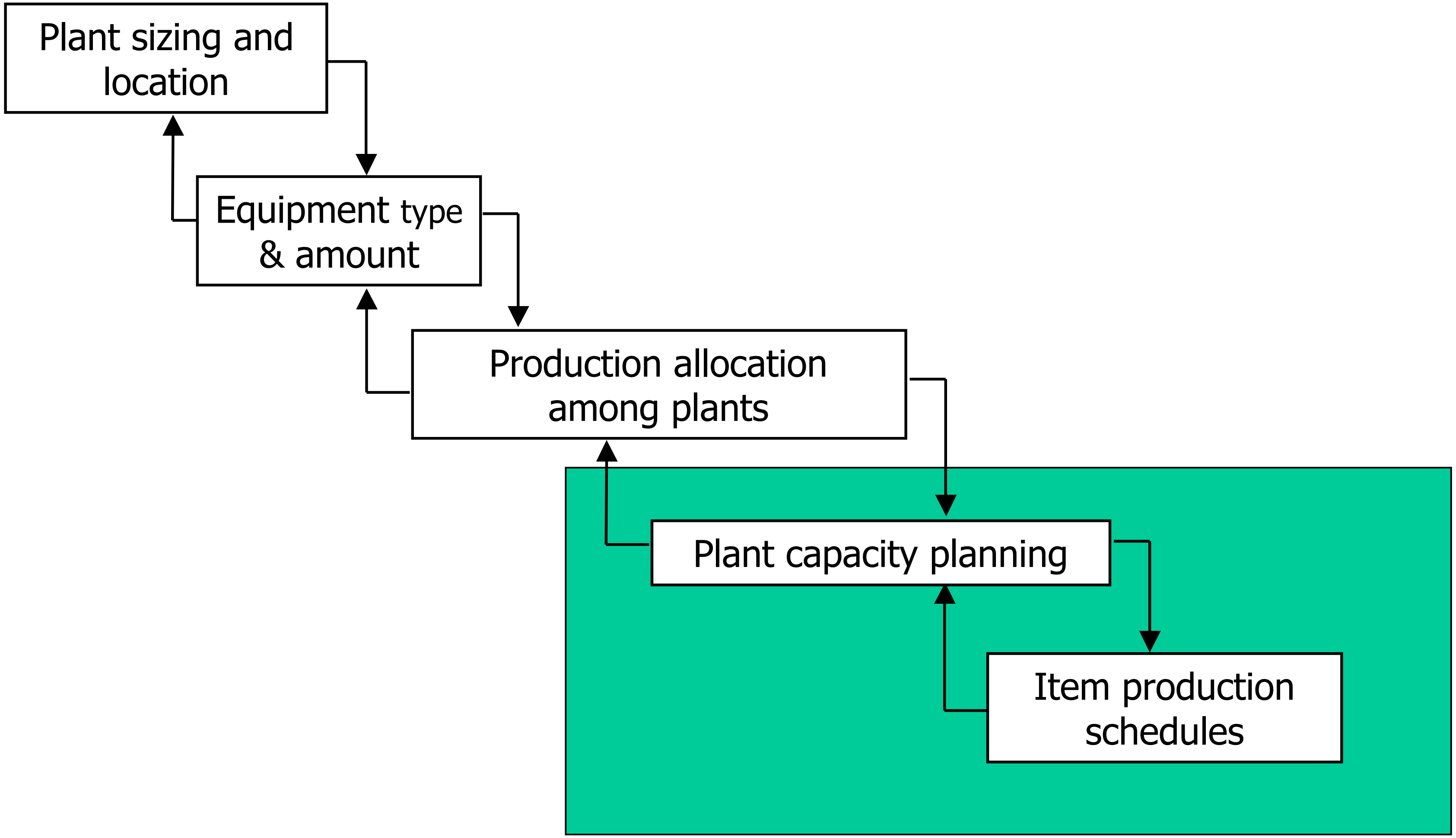
  ➠ ideal layout
- …



High Voltage Capacitors

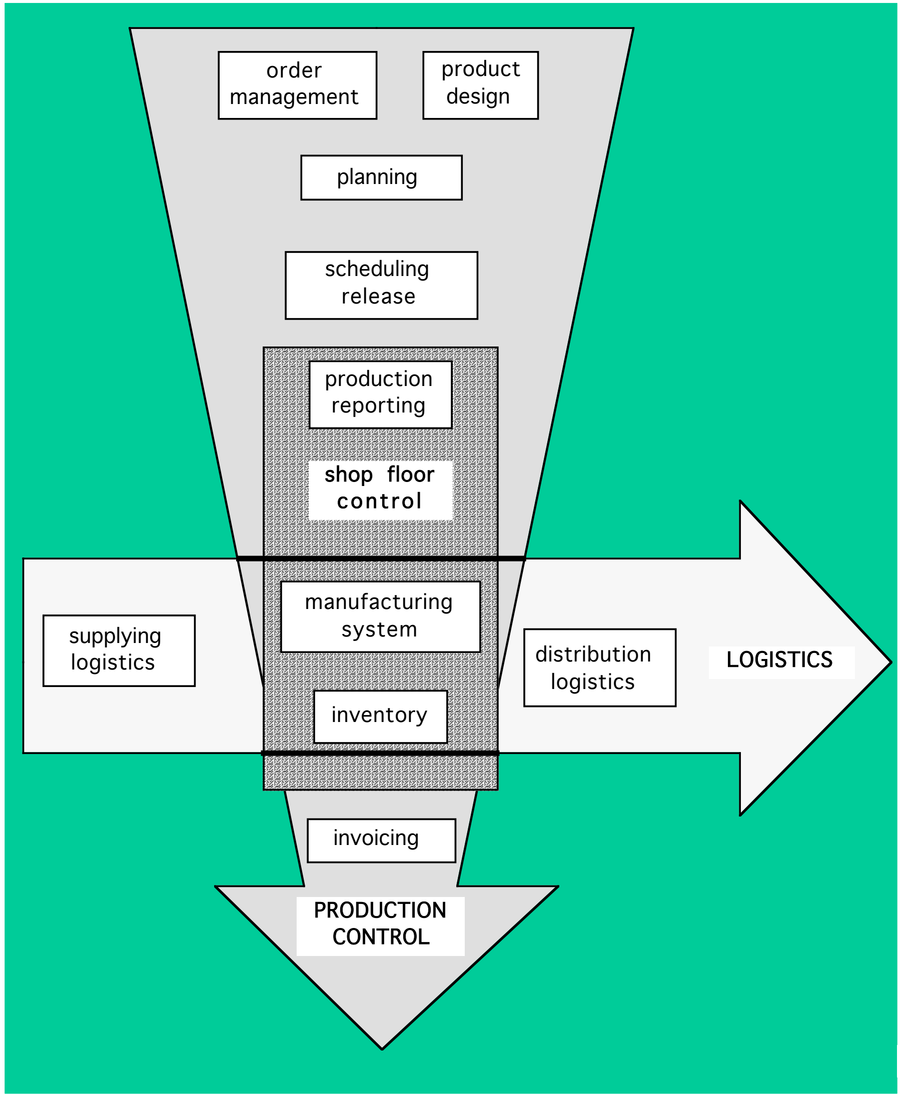
Could you help me ??

A systematic process



Source : Chase & Aquilano, *Production and Operations Management - A Life Cycle Approach*, Fifth Edition, Irwin, 1989

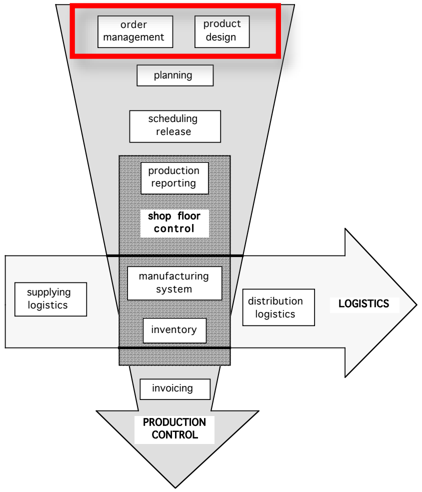
The two last steps in detail



From order to delivery

customer's order

- catalogue
- new product »»» design



order management

- with order forecasting
  (depending on the chosen production type)
- dialogue with inventory management

»»» define the quantities to produce

»»» define the delivery time for the customer

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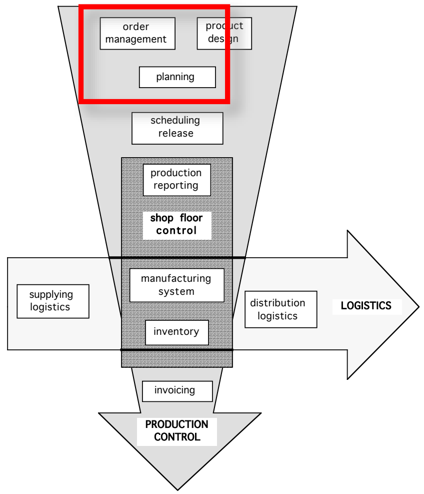
From order to delivery (2)

planning (to determine the delays)

- the set of parts being currently in process
- the set of parts which manufacture is foreseen (planned)

»»» what should we produce ?

»»» when should we produce ? (delays)



From order to delivery (3)

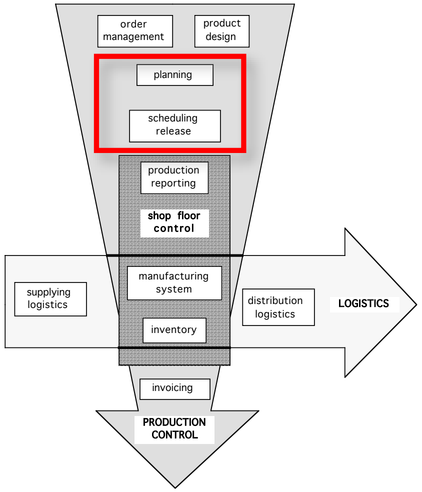
planning

- the delivery times determine when orders have to be given to the suppliers
- dialogue with the purchase management (supply logistics)

scheduling

- the quantities to produce during next planning period are known

»»» how should we produce ?

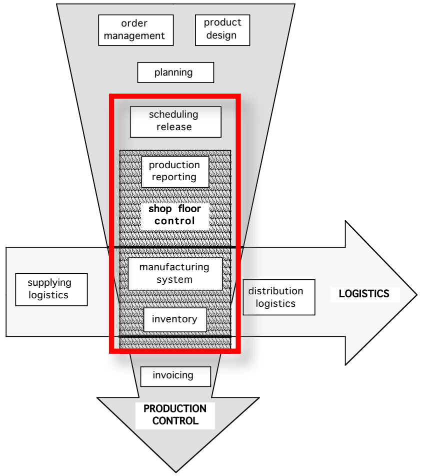


From order to delivery (4)

scheduling

to respect some criteria :

- minimize the work-in-process
- maximize the resource utilization
- minimize the transfer duration



real time control

- the production is released : try to respect as faithfully as possible the work sequence established by the scheduling phase

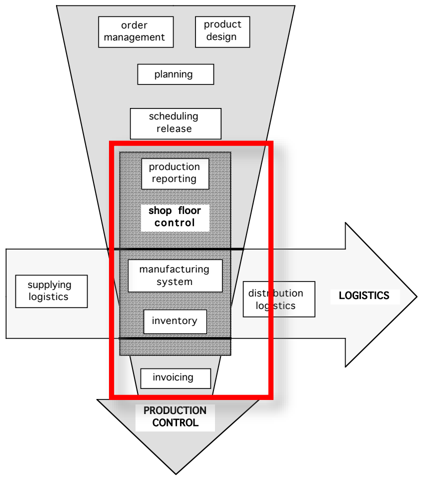
From order to delivery (5)

real time control

- quality control
- maintenance management
- random events management
- …

with invoicing and sending :

»»» production control

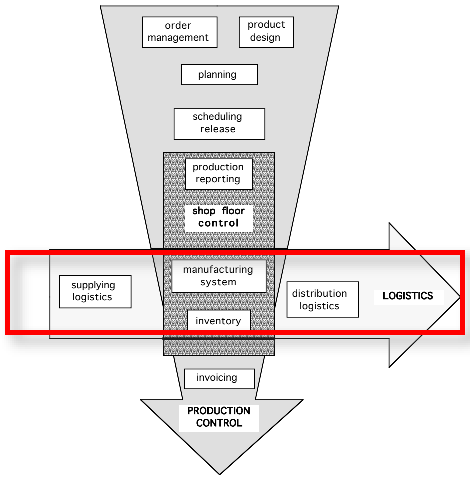


From raw material to finished product

logistics

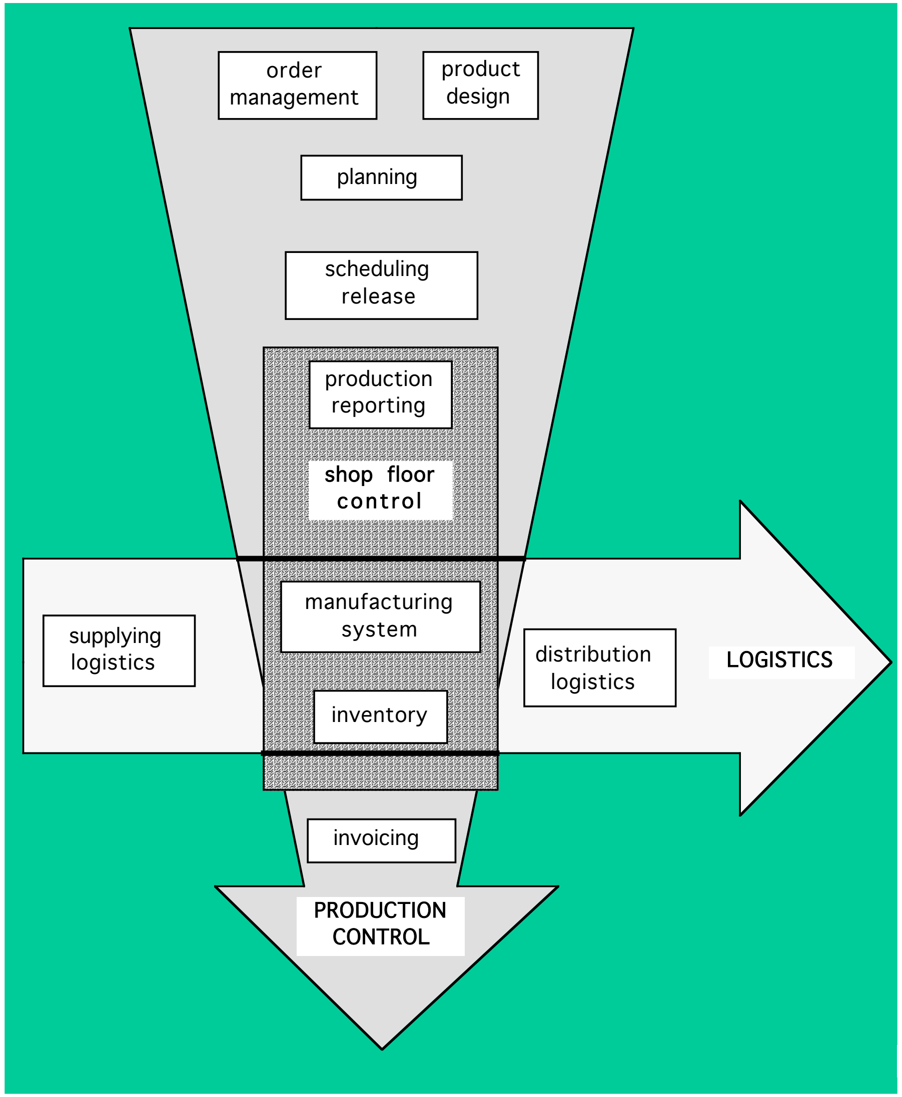
- supply logistics
- inventory management
- distribution logistics

»»» logistics



»»»» integrated production management

Integrated production management



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The advantages of the process

To place each problem in its context !

TO THINK GLOBALLY

TO ACT LOCALLY

For each function (module)

- entering information (input data)
- information treatment
- outgoing information (output data)

∃ OR models for solving each problem !

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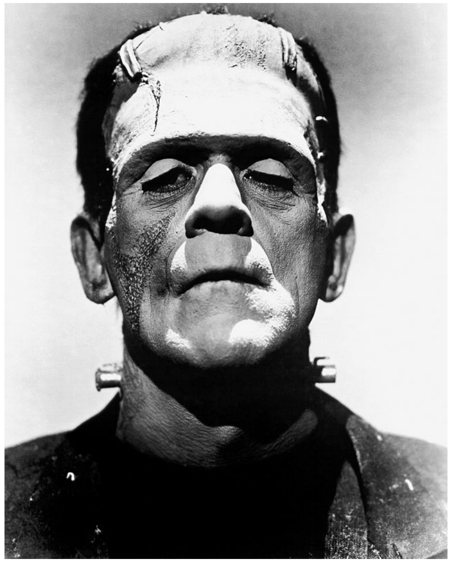
The main disadvantage of the process

Each problem is solved separately !

LOCALLY OPTIMAL

GLOBALLY … PERFECTIBLE

A well-known previous example …



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Integration vs optimality (1)

Optimality 

Integration 

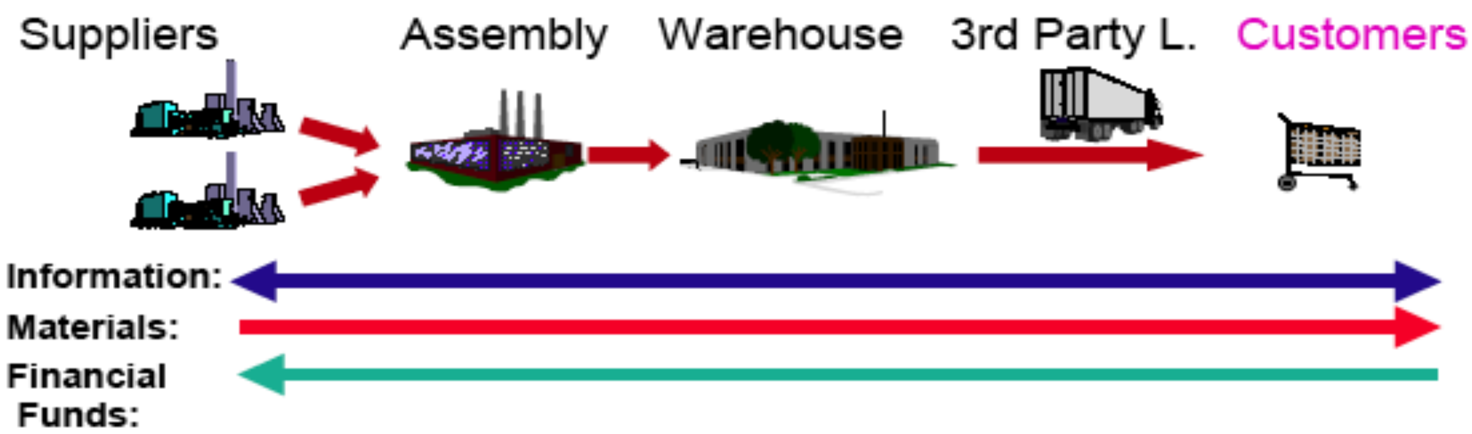
Supply Chain (SC)

"... is a network of organizations that are involved, through upstream and downstream linkages in the different processes and activities that produce value in the form of products and services in the hand of the ultimate customer."

Hartmut Staltler, Darmstadt University of Technology, EURO / INFORMS 2003, Istanbul (Turkey)

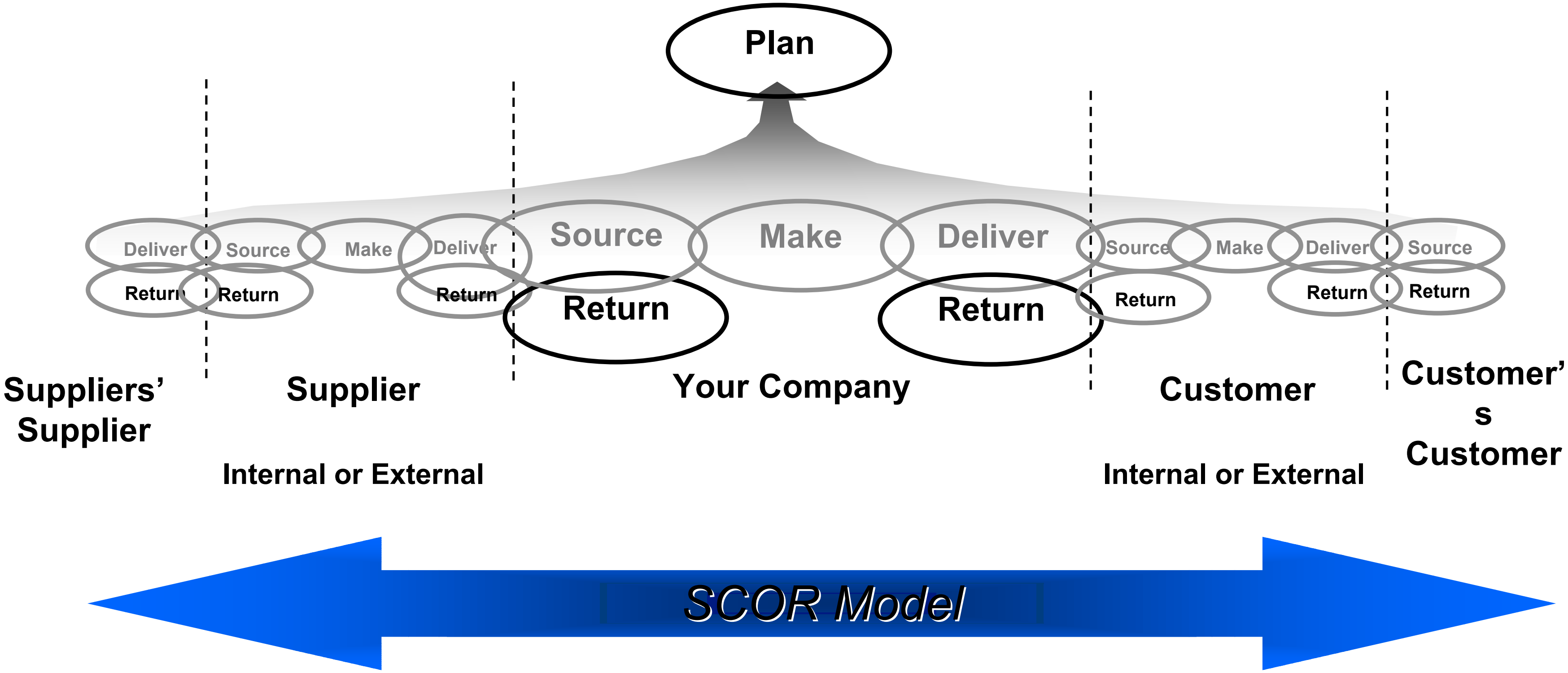
Supply Chain Management (SCM)

... is the task of **integrating** organizational units along a SC and **coordinating** materials, information and financial flows in order to fulfill (ultimate) customer demands with the aim of improving competitiveness of a SC as a whole.



Hartmut Stadtler, Darmstadt University of Technology, EURO / INFORMS 2003, Istanbul (Turkey)

Supply Chain Operations Reference model



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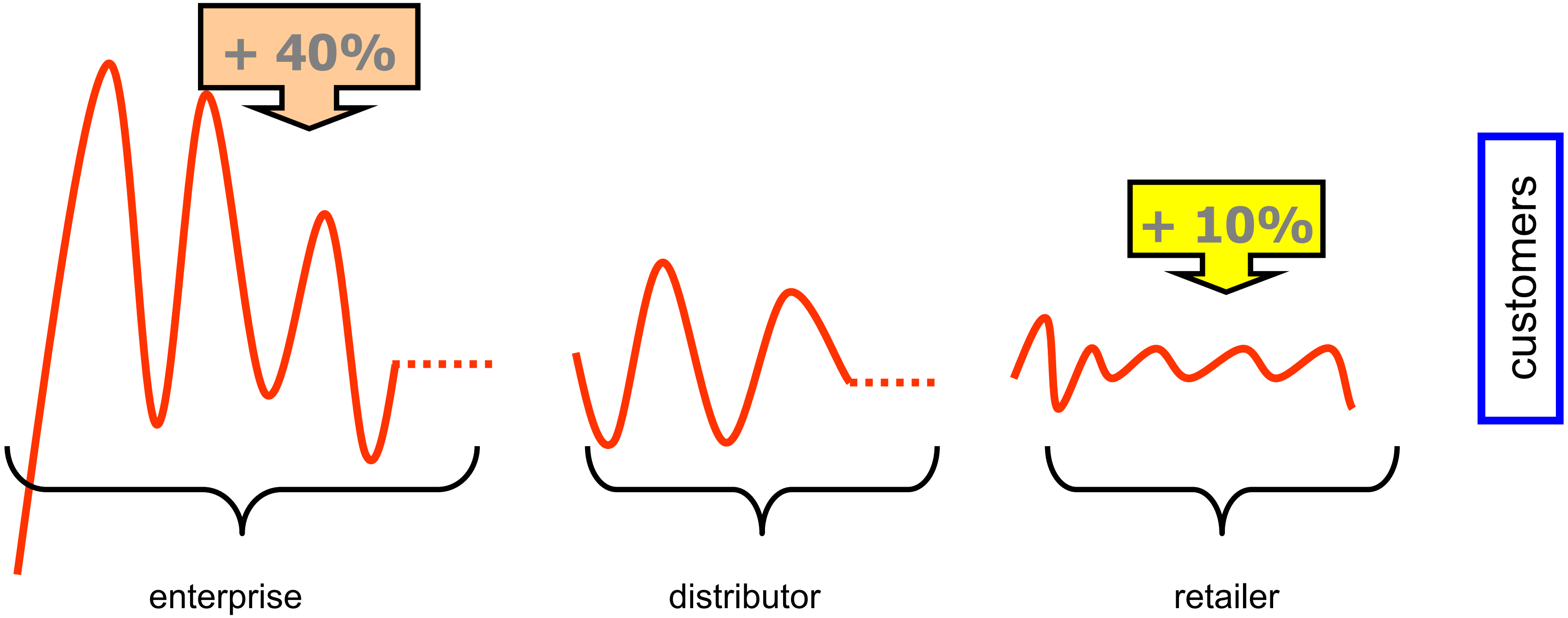
Bullwhip effect



Demand allocation (1)
(Distribution)

Planning situation

- Decision: allocation of demand to facilities
- Objective: minimization of total cost (variable)
- Constraints: plant capacities, demand

From/To	Warsaw	Brussels	Paris	Bilbao	Factory Supply
Berlin	€ 25	€ 35	€ 36	€ 60	15
Genova	€ 55	€ 30	€ 25	€ 25	6
Riga	€ 40	€ 50	€ 80	€ 90	14
Budapest	€ 30	€ 40	€ 66	€ 75	11
Requirements	10	12	15	9	46

Candidate Solution	Warsaw	Brussels	Paris	Bilbao	**Total Shipped**
Berlin	**0**	**0**	**15**	**0**	15
Genova	**0**	**0**	**0**	**6**	6
Riga	**10**	**4**	**0**	**0**	14
Budapest	**0**	**8**	**0**	**3**	11
Requirements	10	12	15	9	46

Cost Calculations	Warsaw	Brussels	Paris	Bilbao	
Berlin	**0**	**0**	**540**	**0**	
Genova	**0**	**0**	**0**	**150**	
Budapest	**400**	**200**	**0**	**0**	
Atlanta	**0**	**320**	**0**	**225**	
				Total Cost=	€ 1'835

Inputs

n	number of plant locations
m	number of markets or demand points
D_j	annual demand from market j
K_i	capacity of plant i
c_{ij}	cost of producing and shipping one unit from factory i to market j

Decision variables

x_{ij}	quantity shipped from plant i to market j

Capacitated plant location (1)

(Production + Distribution)

Planning situation

- Decision: plants to be opened, allocation of demand to facilities
- Objective: minimization of total cost (fixed and variable)
- Constraints: plant capacities, demand

	fi		Aarau	Basel	Bern	Geneva	Lausanne	Locarno	Neuchâtel	St Moritz	Zug	Zurich		ai
		cij												
Delémont	**2'000**		77	41	86	198	148	270	79	318	131	119		**20'000**
Fribourg	**3'000**		115	131	36	138	75	308	46	356	169	157		**40'000**
Luzern	**5'000**		68	102	115	282	219	163	160	224	30	56		**10'000**
Martigny	**2'000**		213	229	134	135	72	193	140	454	267	255		**15'000**
Zurich	**10'000**		47	82	125	292	229	217	170	201	29	10		**10'000**
		bj	**1'000**	**4'000**	**4'000**	**6'000**	**5'000**	**1'000**	**2'000**	**1'000**	**1'000**	**10'000**		

	fi	yi	Aarau	Basel	Bern	Geneva	Lausanne	Locarno	Neuchâtel	St Moritz	Zug	Zurich		ai	ai*yi
Delémont	**2'000**	0	0	0	0	0	0	0	0	0	0	0	0	**20'000**	0
Fribourg	**3'000**	1	1000	4000	4000	6000	5000	1000	2000	0	1000	1000	25000	**40'000**	40000
Luzern	**5'000**	0	0	0	0	0	0	0	0	0	0	0	0	**10'000**	0
Martigny	**2'000**	0	0	0	0	0	0	0	0	0	0	0	0	**15'000**	0
Zurich	**10'000**	1	0	0	0	0	0	0	0	1000	0	9000	10000	**10'000**	10000
	13'000	2	1000	4000	4000	6000	5000	1000	2000	1000	1000	10000	3'003'000		
		2	**1'000**	**4'000**	**4'000**	**6'000**	**5'000**	**1'000**	**2'000**	**1'000**	**1'000**	**10'000**			
														3'016'000	

Capacitated plant location (2)

(Production + Distribution)

Inputs

n	number of potential plant locations
m	number of markets or demand points
D_j	annual demand from market j
K_i	potential capacity of plant i
f_i	annualized fixed cost of keeping plant i open
c_{ij}	cost of producing and shipping one unit from factory i to market j

Decision variables

y_i	= 1, if plant i is open; = 0, otherwise
x_{ij}	quantity shipped from plant i to market j

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Capacitated plant and warehouse location (1)

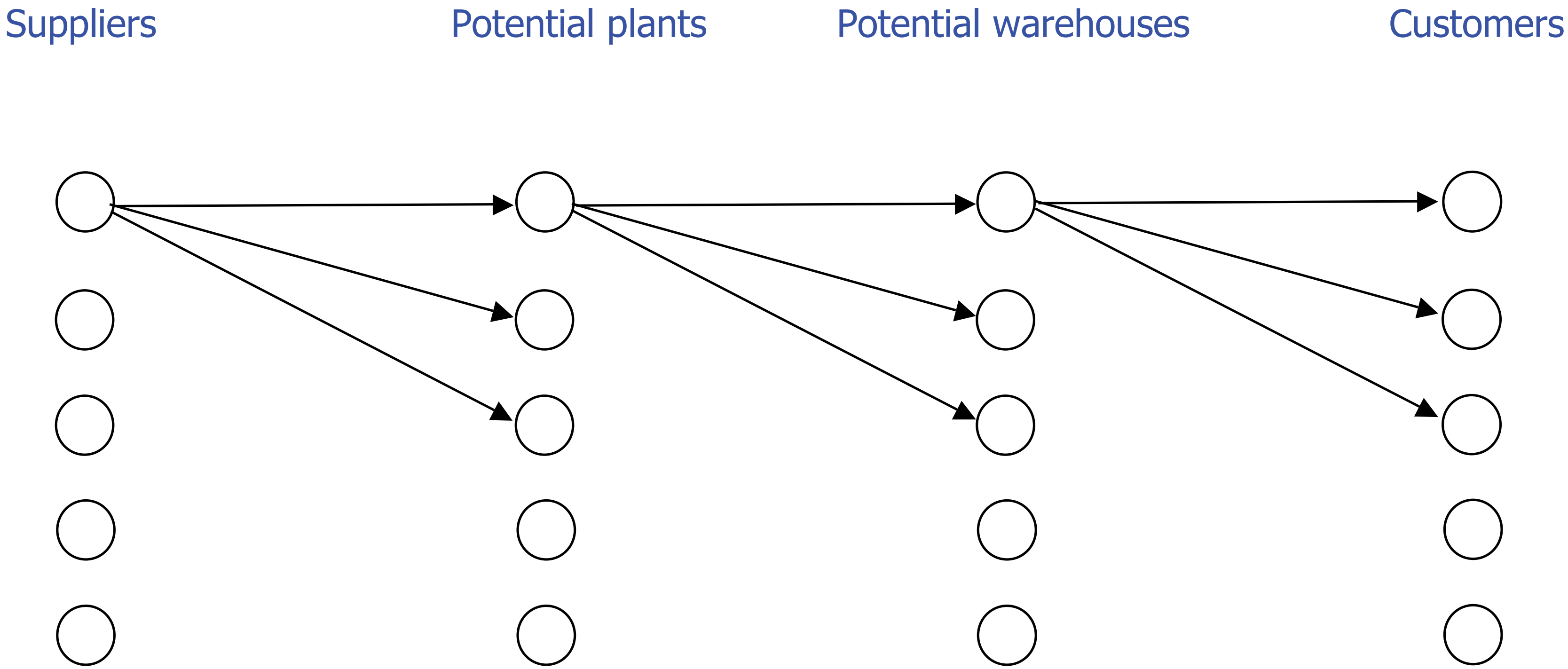
(Production + Warehousing + Distribution)

Planning situation

- Decision: plants and warehouses to be opened, allocation of demand to warehouses
- Objective: maximize total profit
- Constraints: plant capacities, warehouse capacities, demand

Capacitated plant and warehouse location (2)

(Production + Warehousing + Distribution)



Capacitated plant and warehouse location (3)

(Production + Warehousing + Distribution)

Inputs

m	number of markets or demand points
n	number of potential plant locations
l	number of suppliers
t	number of potential warehouse locations
D_j	annual demand from customer j
K_i	potential capacity of plant at site i
S_h	supply capacity at supplier h
W_e	potential warehouse capacity at site e
F_i	fixed cost of locating a plant at site i
f_e	fixed cost of locating a warehouse at site e
c_{hi}	cost of shipping one unit from supply source h to factory i
c_{ie}	cost of producing and shipping one unit from factory i to warehouse e
c_{ej}	cost of shipping one unit from warehouse e to customer j

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Capacitated plant and warehouse location (4)

(Production + Warehousing + Distribution)

Decision variables

y_i = 1, if plant is located at site *i* ; = 0, otherwise
y_e = 1, if warehouse is located at site *e* ; = 0, otherwise
x_{ej} quantity shipped from warehouse *e* to market *j*
x_{ie} quantity shipped from factory at site *i* to warehouse *e*
x_{hi} quantity shipped from supplier *h* to factory at site *i*

Objective : minimize the total cost

$$\text{Min.} \sum_{i=1}^{n} F_i y_i + \sum_{e=1}^{t} f_e y_e + \sum_{h=1}^{l} \sum_{i=1}^{n} c_{hi} x_{hi} + \sum_{i=1}^{n} \sum_{e=1}^{t} c_{ie} x_{ie} + \sum_{e=1}^{t} \sum_{j=1}^{m} c_{ej\,xej}$$

- supply may not exceed supplier's capacity

$$\sum_{i=1}^{n} x_{hi} \leq S_h \qquad (h = 1,\ldots,l)$$

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Capacitated plant and warehouse location (5)

(Production + Warehousing + Distribution)

- production quantity may not exceed raw material supply

$$\sum_{h=1}^{l} x_{hi} - \sum_{e=1}^{t} x_{ie} \geq 0 \quad (i = 1,\ldots,n)$$

- production quantity may not exceed plant capacity

$$\sum_{e=1}^{t} x_{ie} \leq K_i y_i \qquad (i = 1,\ldots,n)$$

- shipment quantity may not exceed total delivery

$$\sum_{i=1}^{n} x_{ie} - \sum_{j=1}^{m} x_{ej} \geq 0 \quad (e = 1,\ldots,t)$$

- shipment quantity may not exceed warehouse capacity

$$\sum_{j=1}^{m} x_{ej} \leq W_e y_e \qquad (e = 1,\ldots,t)$$

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Capacitated plant and warehouse location (6)

(Production + Warehousing + Distribution)

- demand of each customer satisfied

$$\sum_{e=1}^{t} x_{ej} = D_j \qquad (j = 1,\dots,m)$$

- each factory or warehouse either open or closed

$$y_i, y_e \in \{0,1\} \qquad (i = 1,\dots,n \ ; \ e = 1,\dots,t)$$

- non-negativity quantities

$$x_{ej}, x_{ie}, x_{hi} \geq 0 \qquad (i = 1,\dots,n \ ; \ j = 1,\dots,m \ ; \ e = 1,\dots,t)$$

Integration vs optimality (2)

	Modeling	Solving
Optimality		
Integration		

How to solve these problems ?

Exact methods

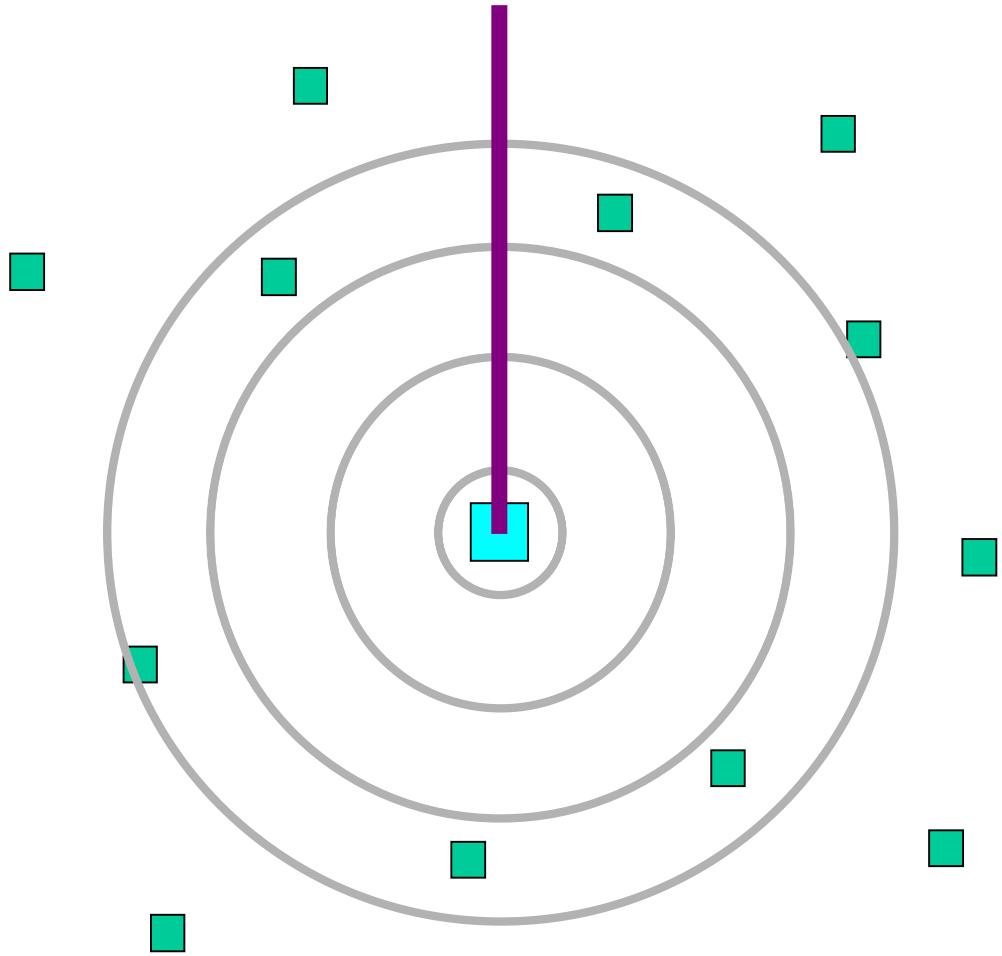
- general (not specific for a problem)
- commercial software (more and more powerful)
- inadequate for medium / large instances

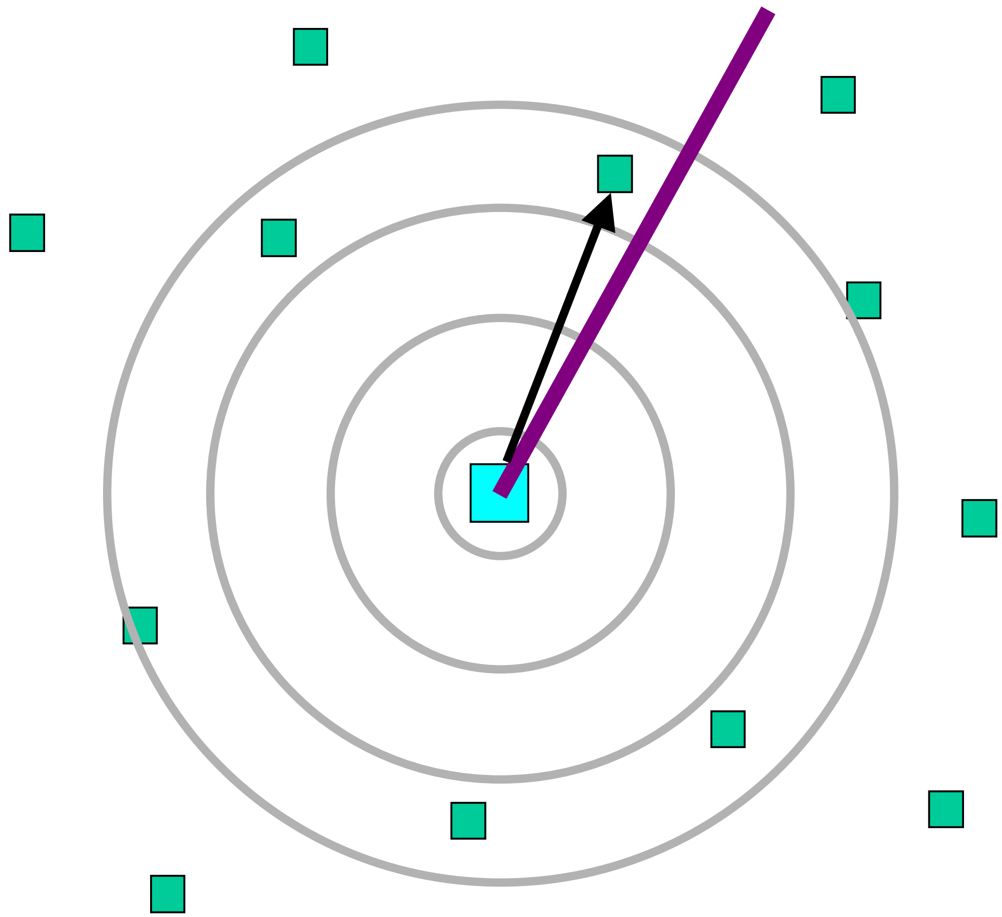
Meta - heuristic methods

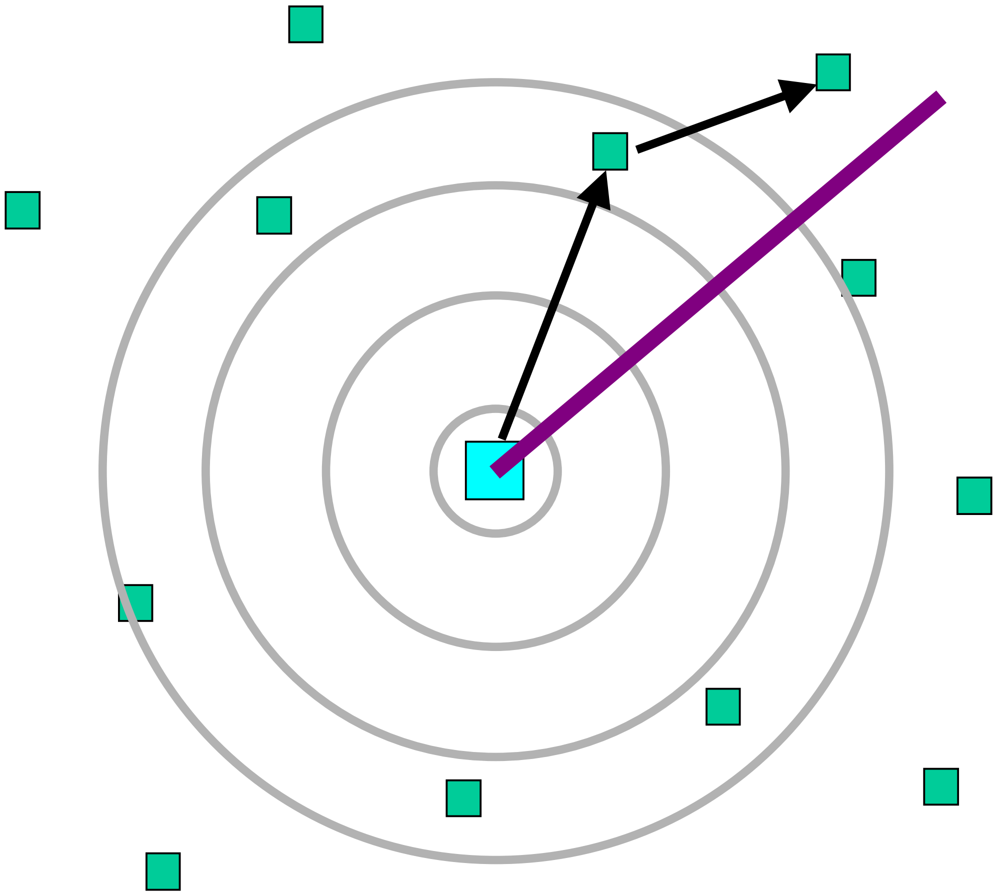
- constructive methods
- *local search methods*
- *evolutionary algorithms*
- *hybrid algorithms*
- *…*

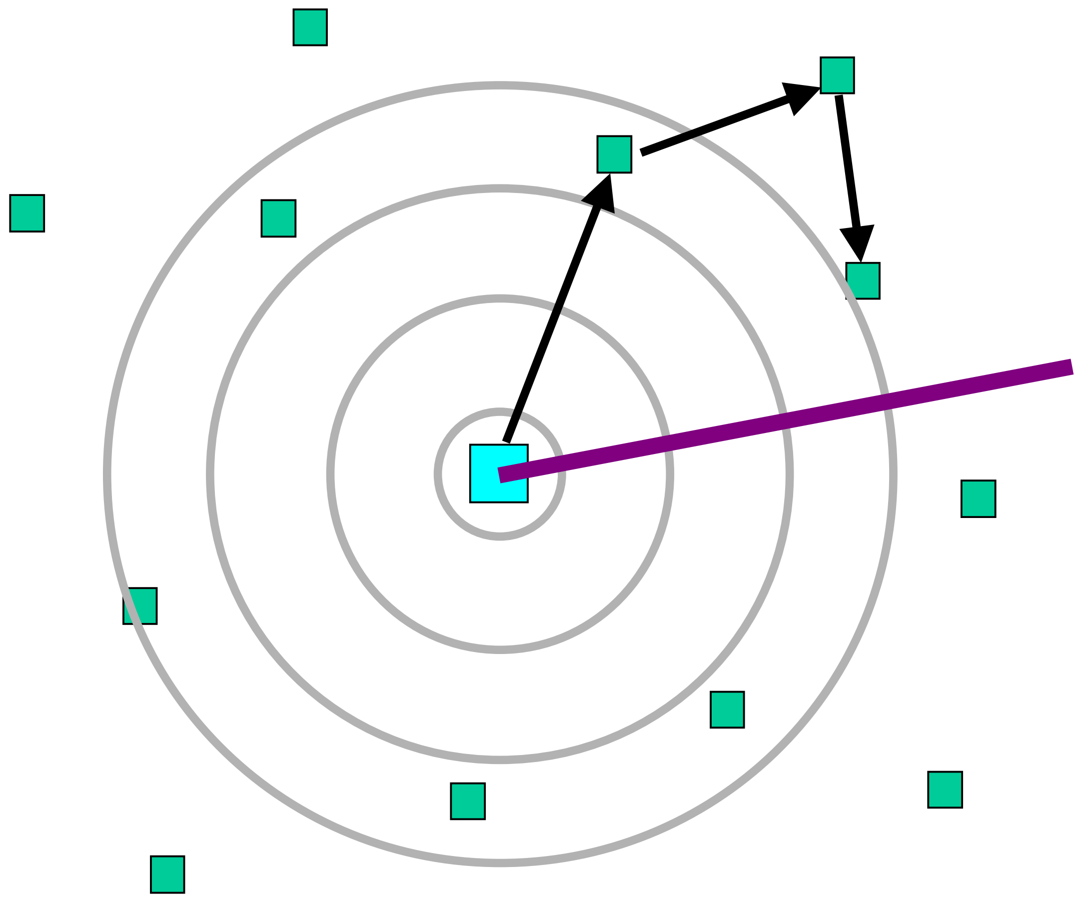
A heuristic method for the VRP

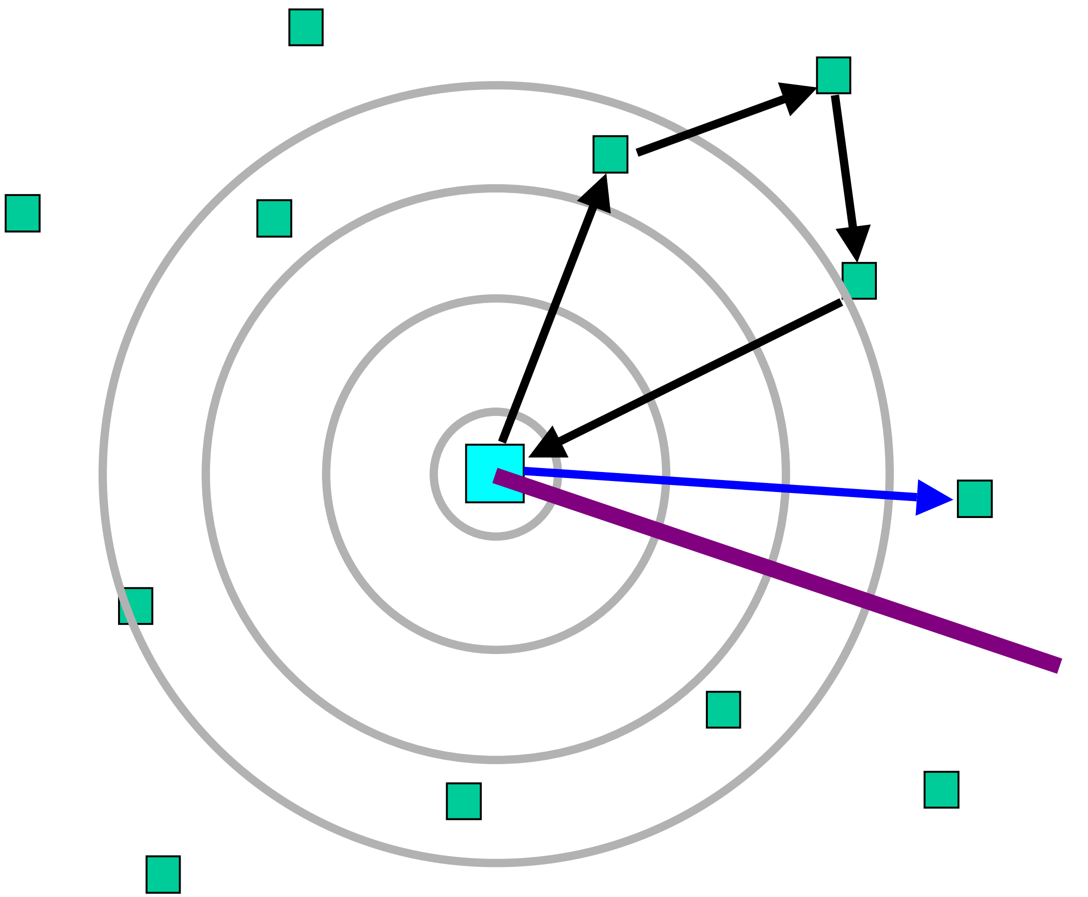
Sweep algorithm

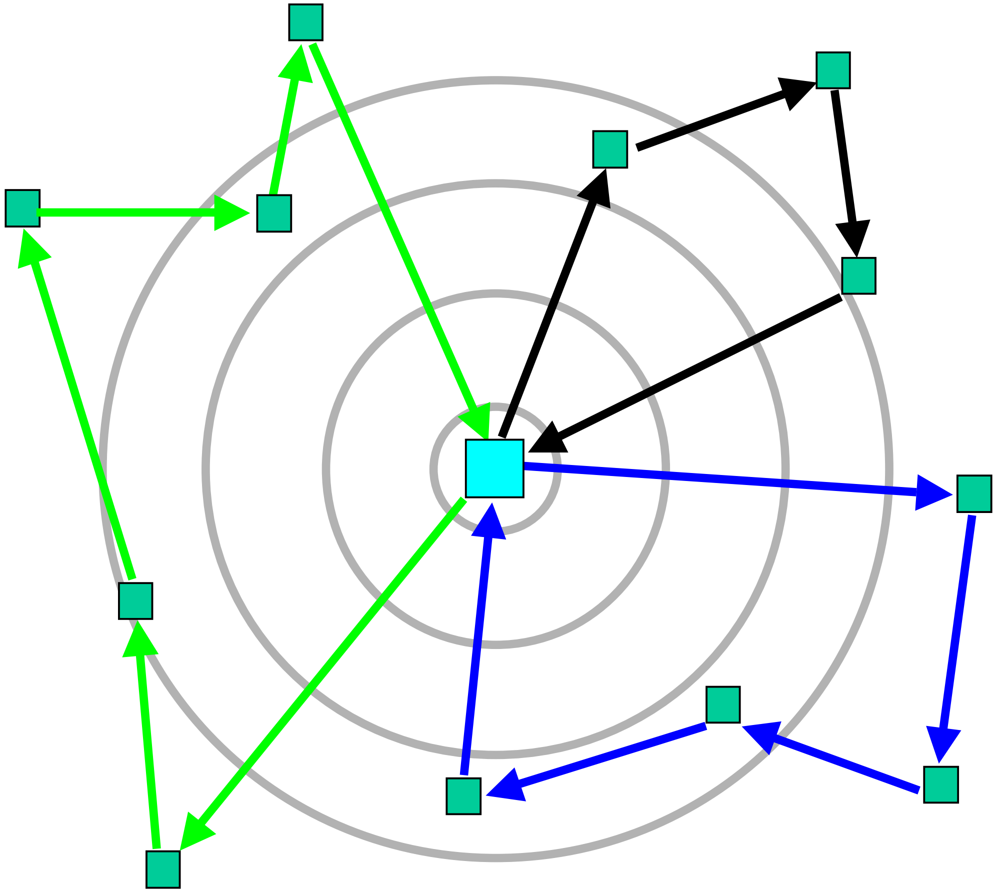




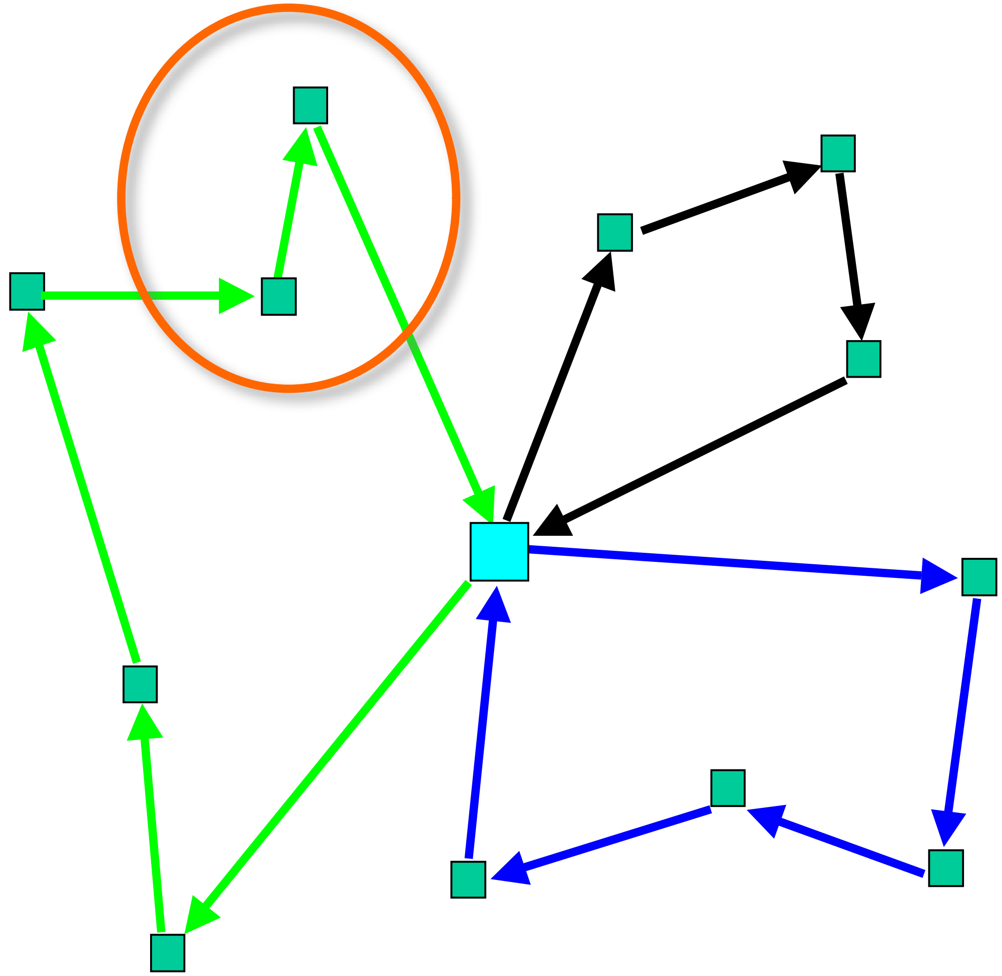




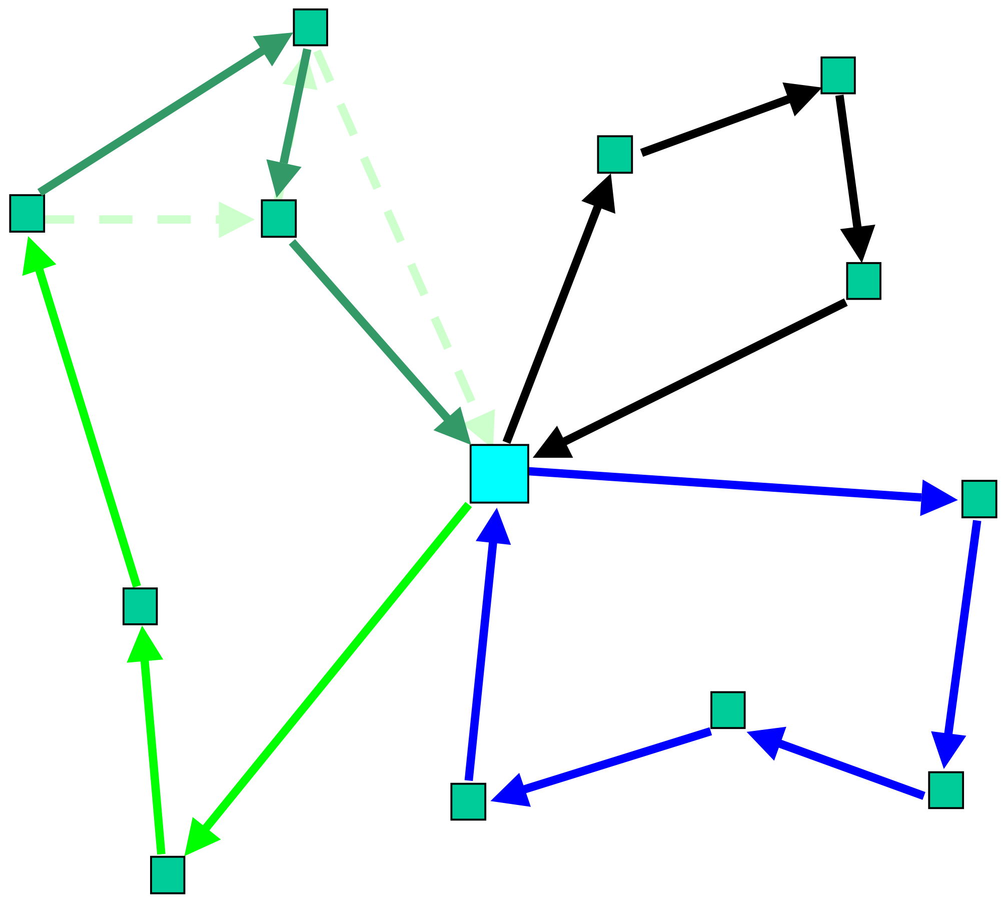




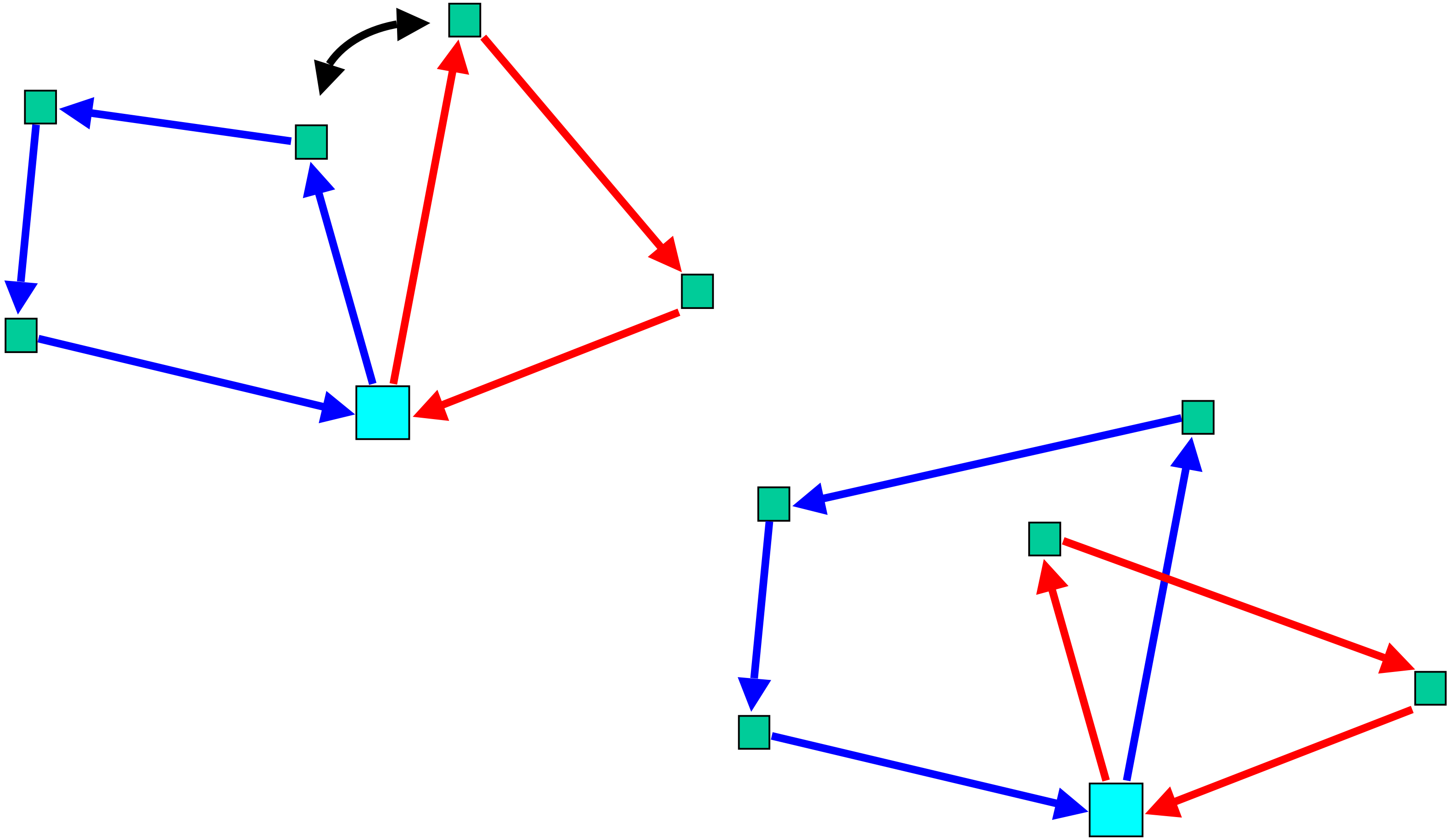
Local search (1)



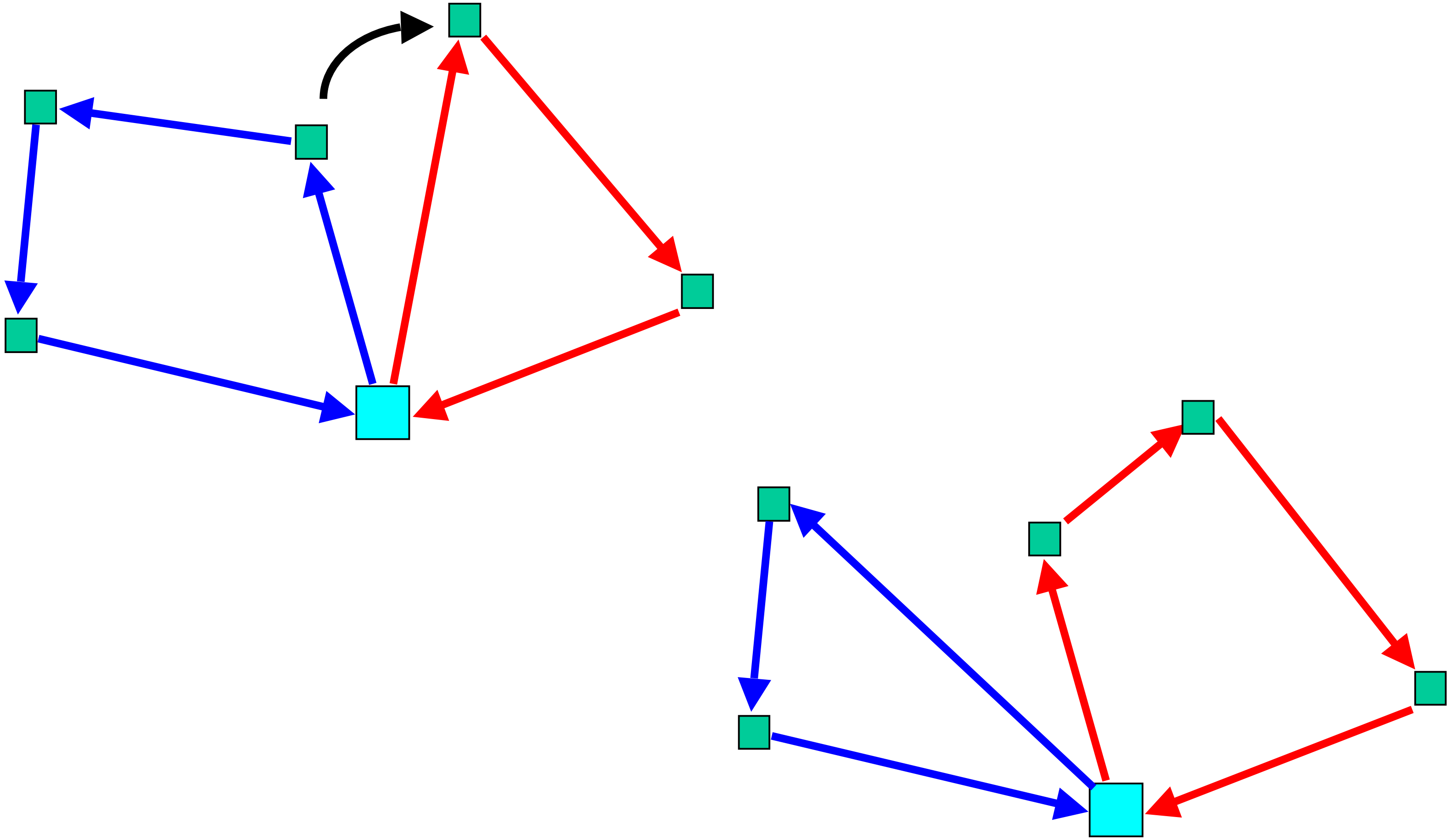
Local search (2)



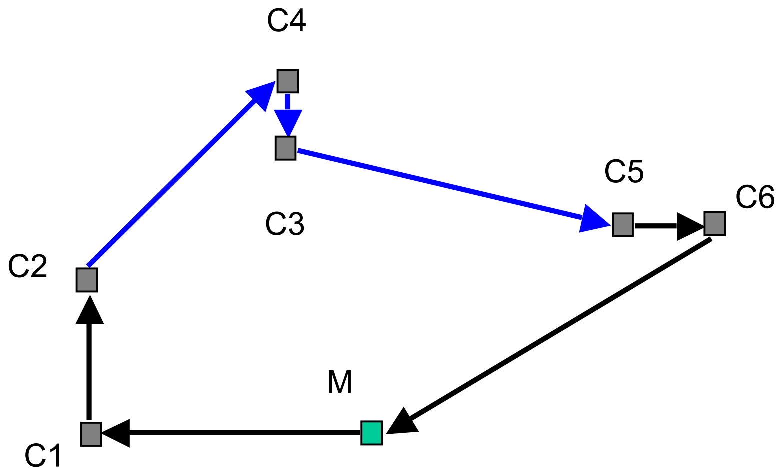
Exchange

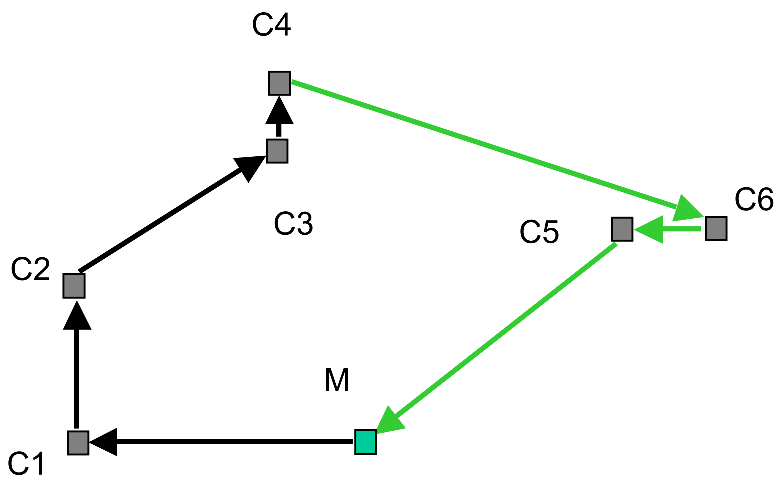


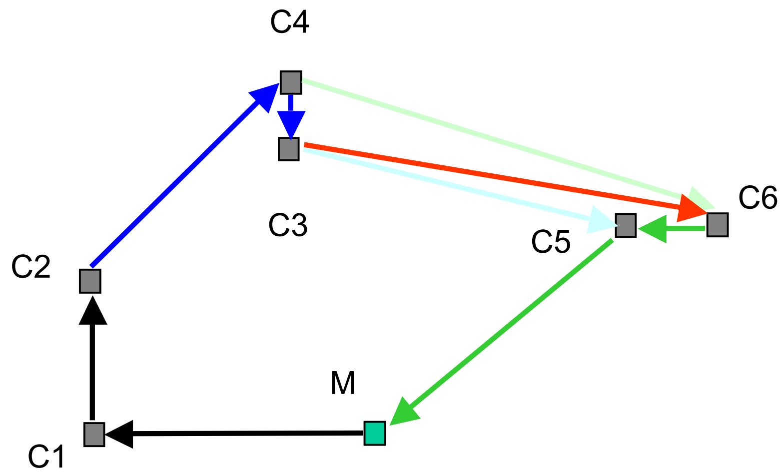
Delete / insert



Evolutionary algorithms





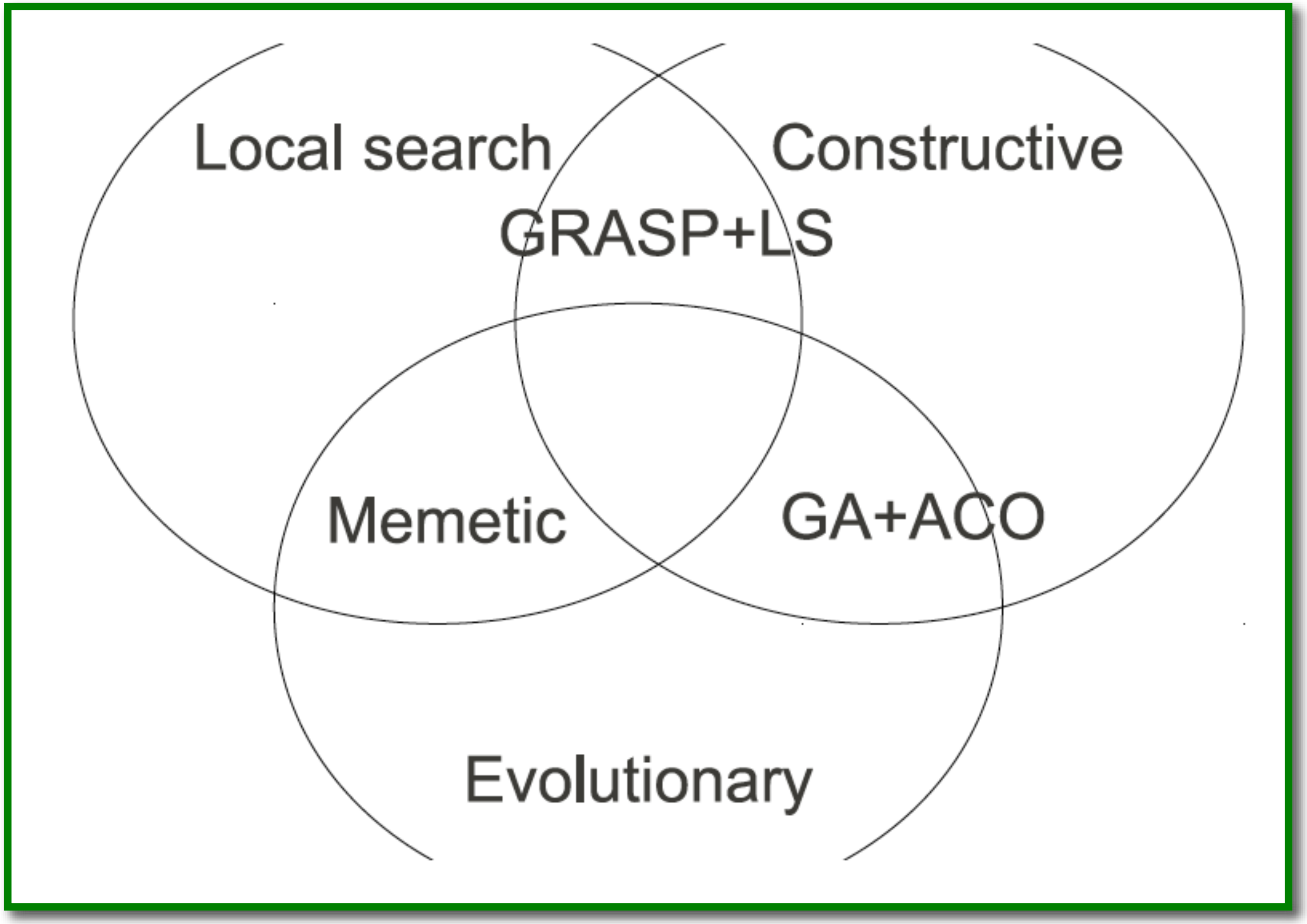


Meta-heuristics

An impressive collection …

- Tabu Search
- Variable neighbourhood search
- Iterated local search
- Guided local
- Kangaroo algorithm
- Simulated annealing
- Deterministic annealing
- Great deluge algorithm
- GRASP
- Multi-start descent
- Evolutionary algorithms
- Genetic algorithms
- Scatter search
- Ant colony optimization
- Bee colony optimization
- Bat-inspired algorithm
- …

Hybrid algorithms



Meta-heuristics & exact methods

Can we combine the strength of exact methods with the strength of (meta-)heuristics ?

YES, thanks to matheuristics !

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Universiteit Antwerpen - ANT/OR

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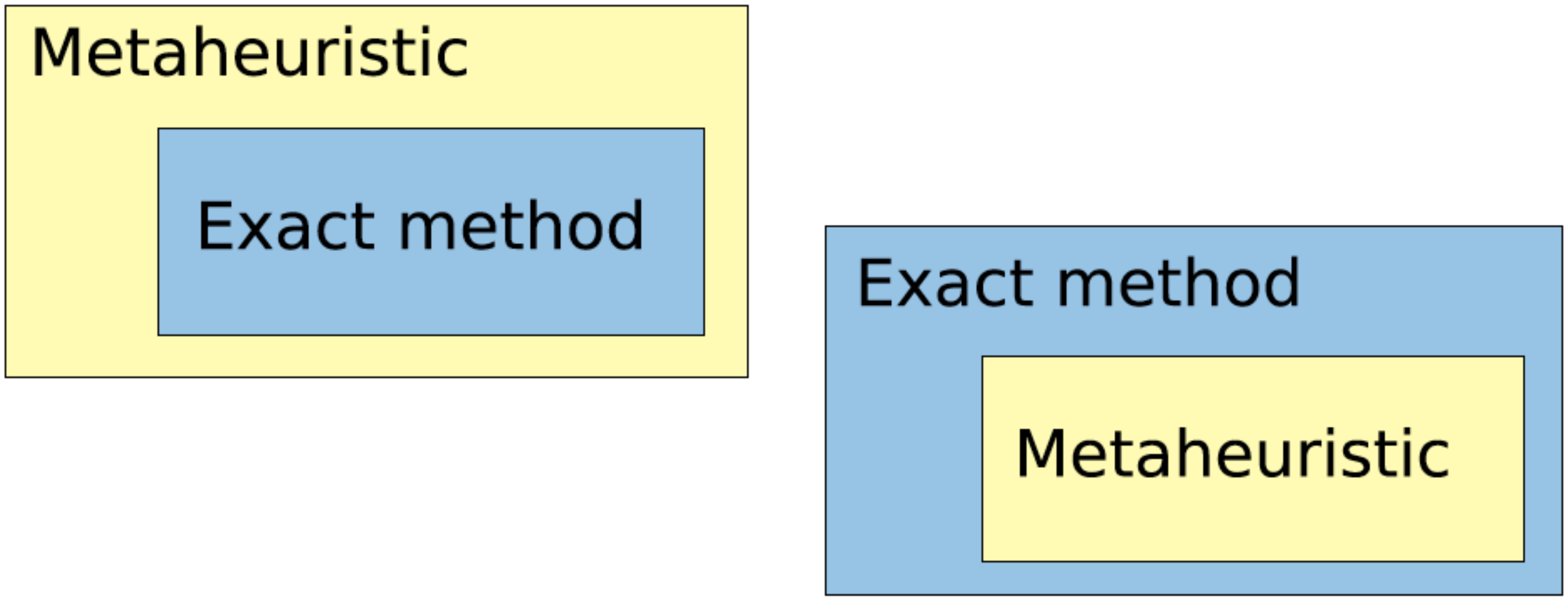
Matheuristics ?

Definition

Matheuristics combine linear or mixed-integer programming (LP/MIP) approaches with metaheuristics

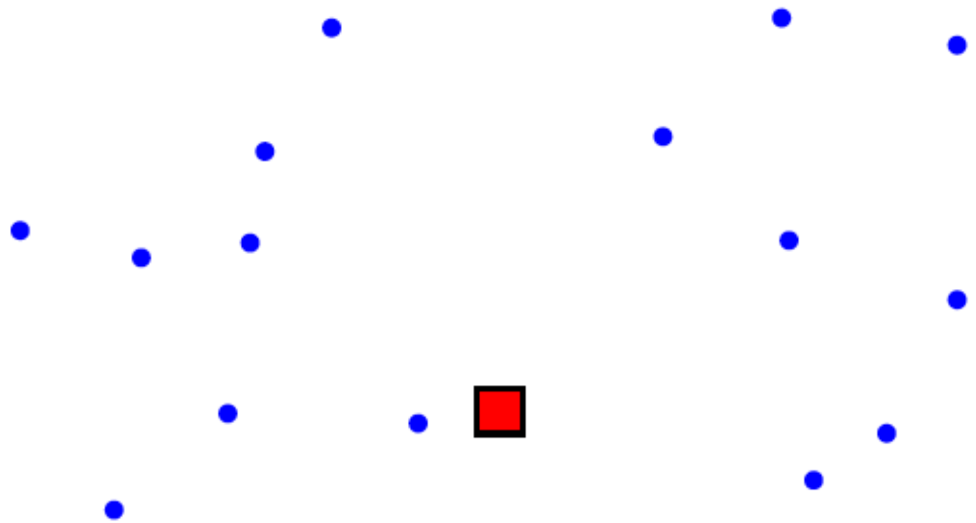


The School Bus Routing Problem (1)

- a school

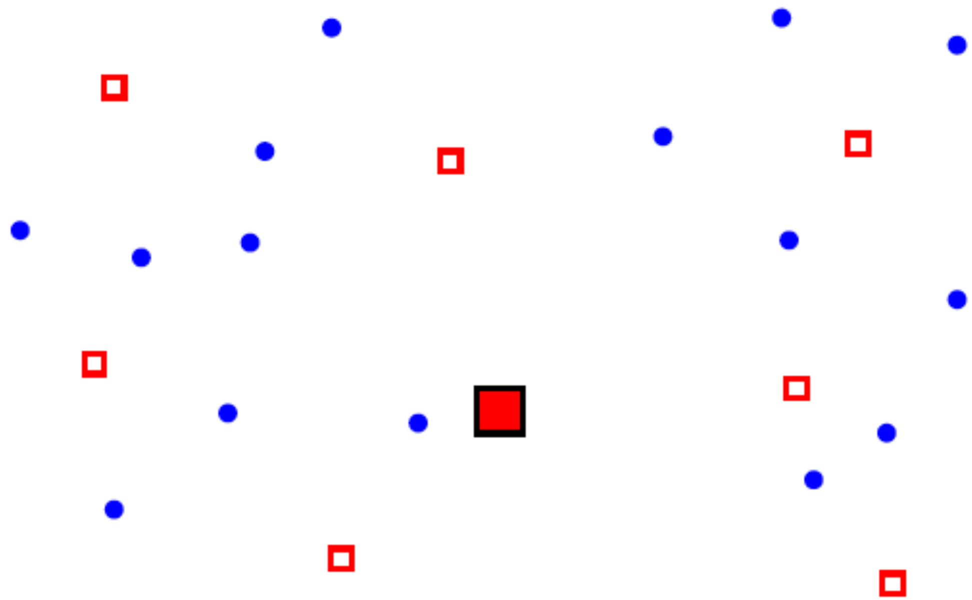
The School Bus Routing Problem (1)

- a school
- a set of students



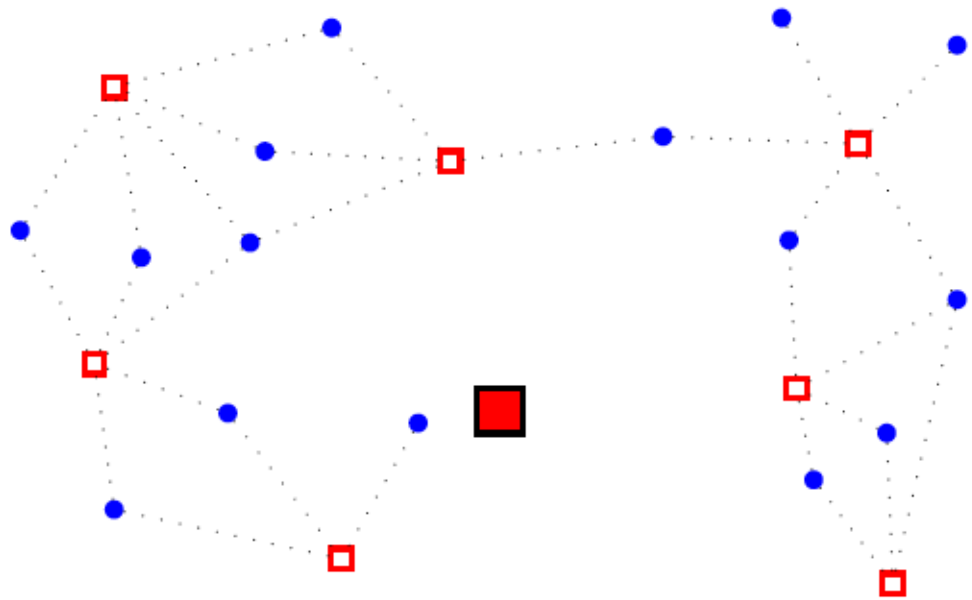
The School Bus Routing Problem (1)

- a school
- a set of students
- a set of potential bus stops

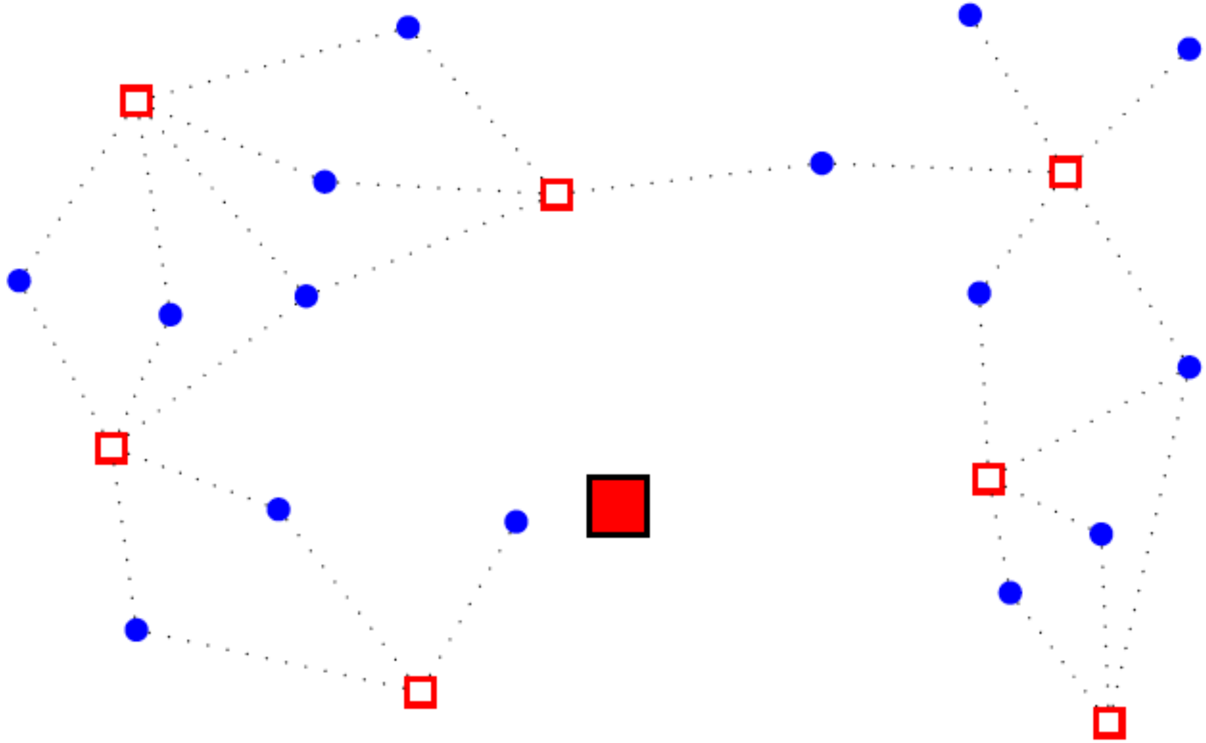


The School Bus Routing Problem (1)

- a school
- a set of students
- a set of potential bus stops
- a maximum walking distance (students $\rightarrow$ stops)



The School Bus Routing Problem (2)



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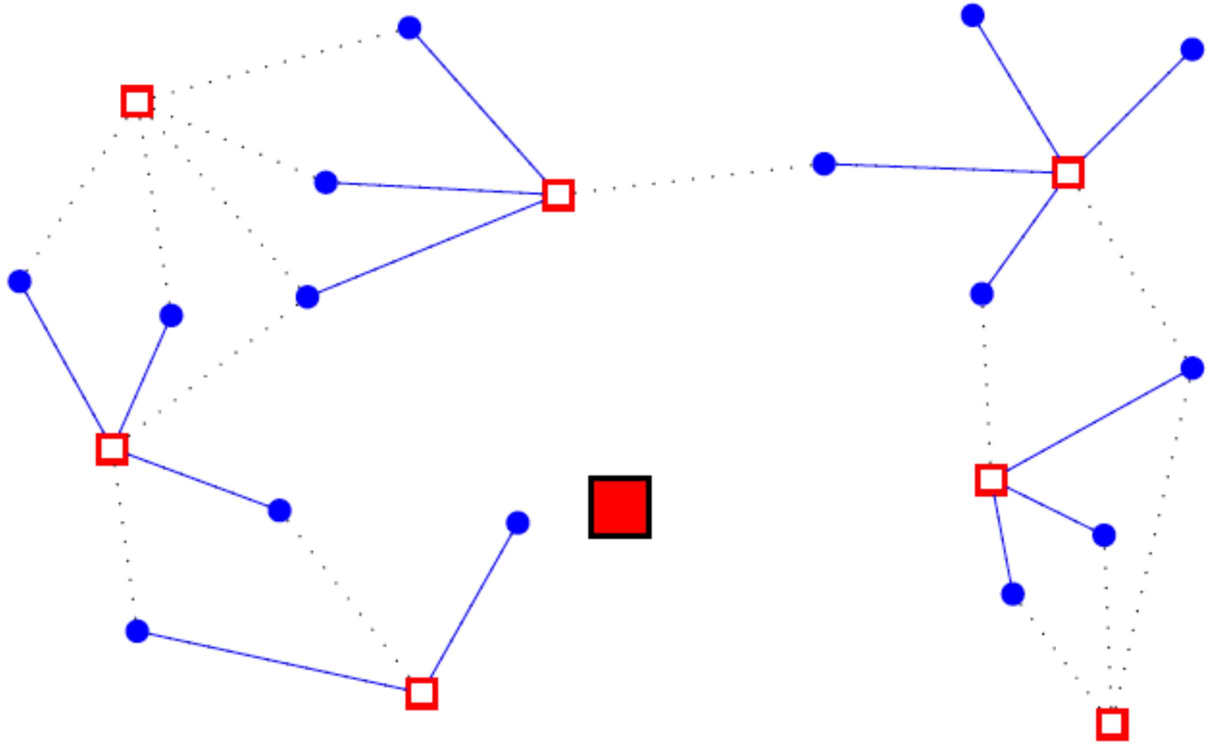
The School Bus Routing Problem (2)

- students are assigned to bus stops



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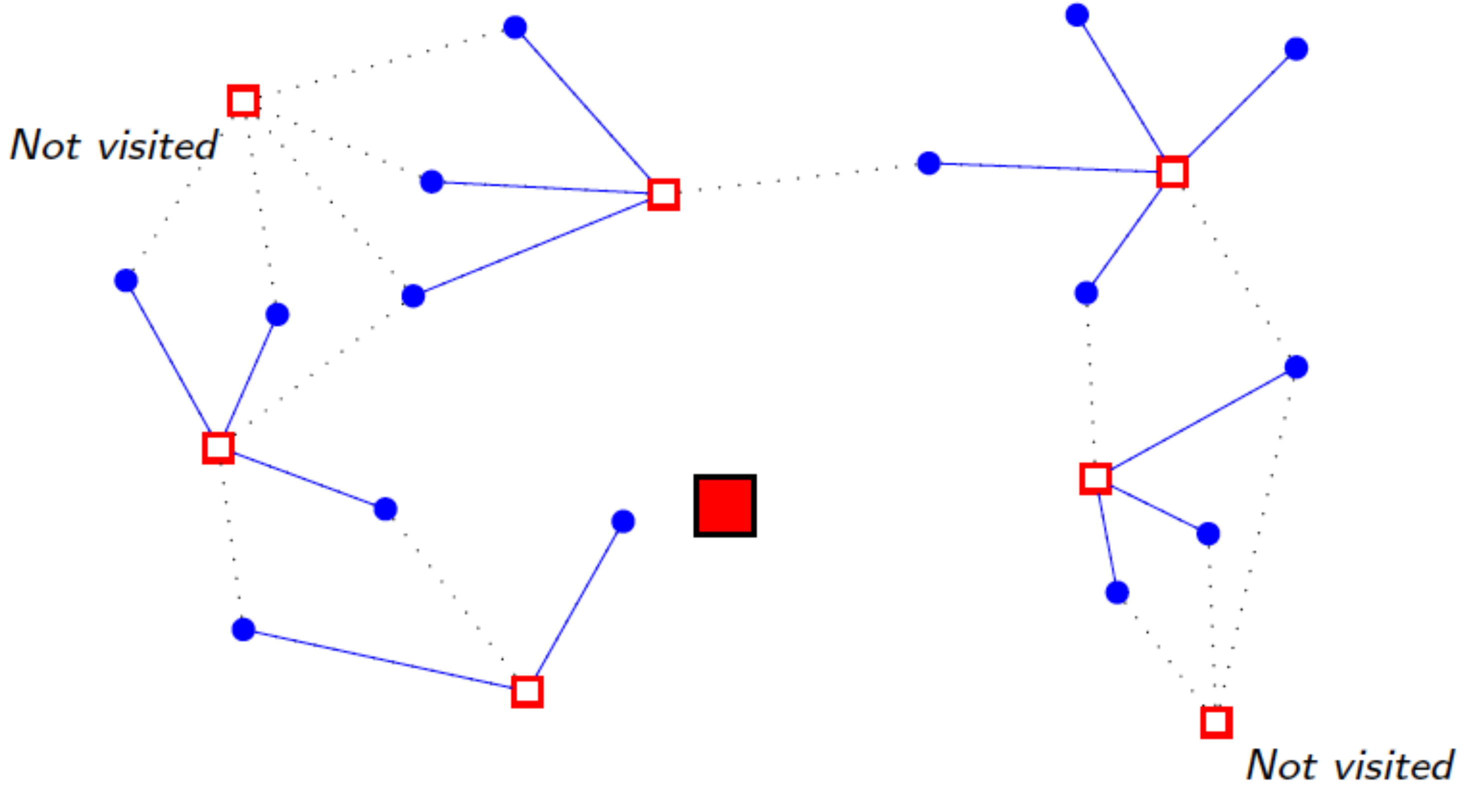
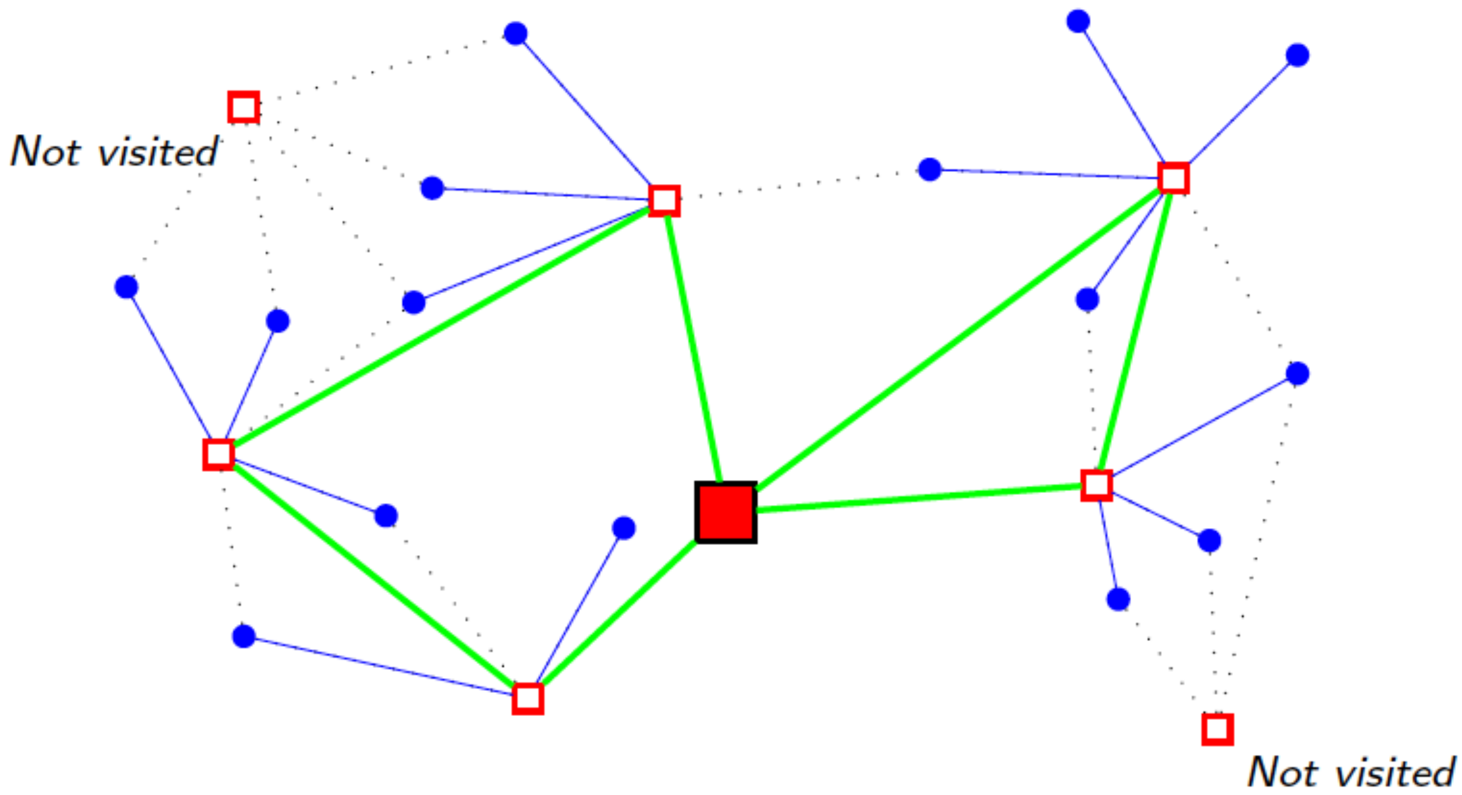
The School Bus Routing Problem (2)

- students are assigned to bus stops
- two potential bus stops are not visited



The School Bus Routing Problem (2)

- students are assigned to bus stops
- two potential bus stops are not visited
- two bus tours are created



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Differences with Basic VRP

Decisions

- How many routes?
- Allocate stops to route
- Order stops within a route
- Allocate students to stops

Objective: Minimize total distance

Restrictions

- Vehicle capacity restrictions
- Unit-stop restrictions
- etc.

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Interesting property (1)

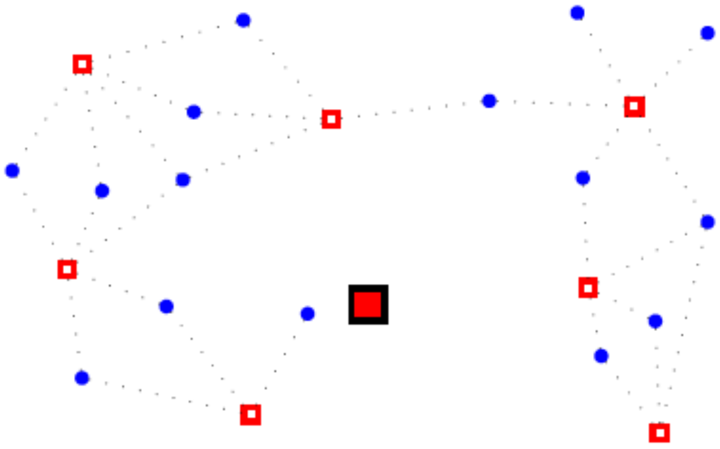
- Special case of the Transportation problem
- Students → supply points
  Routes → demand points

$$\min \sum_{i \in S} \sum_{j \in R} c_{ij} x_{ij} \qquad (1)$$

$$\sum_{j \in R} x_{ij} = 1 \quad \forall i \in S \qquad (2)$$

$$\sum_{i \in S} x_{ij} \leq K \quad \forall j \in R \qquad (3)$$

$$x_{ij} \in \{0, 1\} \qquad (4)$$



Interesting property (2)

Once the routes are known …

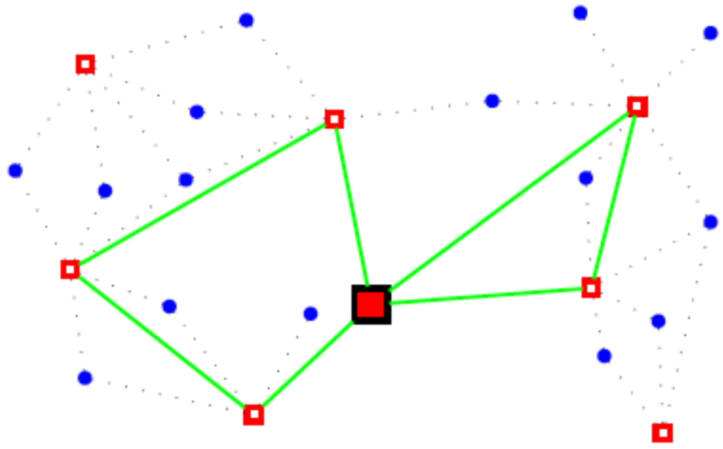
- Special case of the Transportation problem
- Students → supply points
  Routes → demand points

$$\min \sum_{i \in S} \sum_{j \in R} c_{ij} x_{ij} \qquad (1)$$

$$\sum_{j \in R} x_{ij} = 1 \quad \forall i \in S \qquad (2)$$

$$\sum_{i \in S} x_{ij} \leq K \quad \forall j \in R \qquad (3)$$

$$x_{ij} \in \{0, 1\} \qquad (4)$$



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Interesting property (3)

The assignment of students to stops is a simple ...

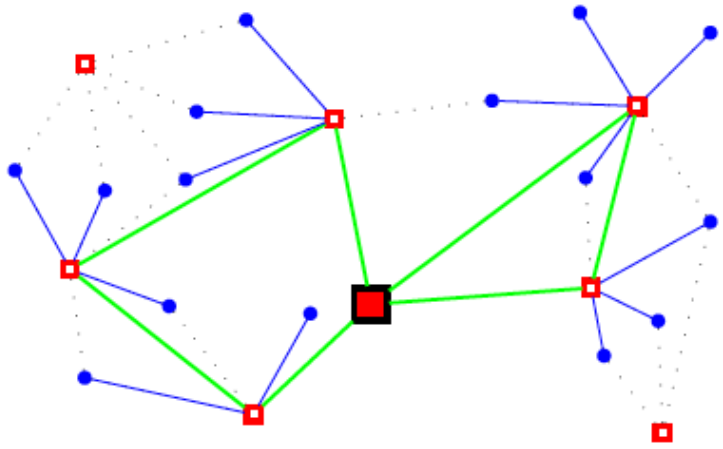
- Special case of the Transportation problem
- Students → supply points
  Routes → demand points

$$\min \sum_{i \in S} \sum_{j \in R} c_{ij} x_{ij} \quad (1)$$

$$\sum_{j \in R} x_{ij} = 1 \quad \forall i \in S \quad (2)$$

$$\sum_{i \in S} x_{ij} \leq K \quad \forall j \in R \quad (3)$$

$$x_{ij} \in \{0, 1\} \quad (4)$$



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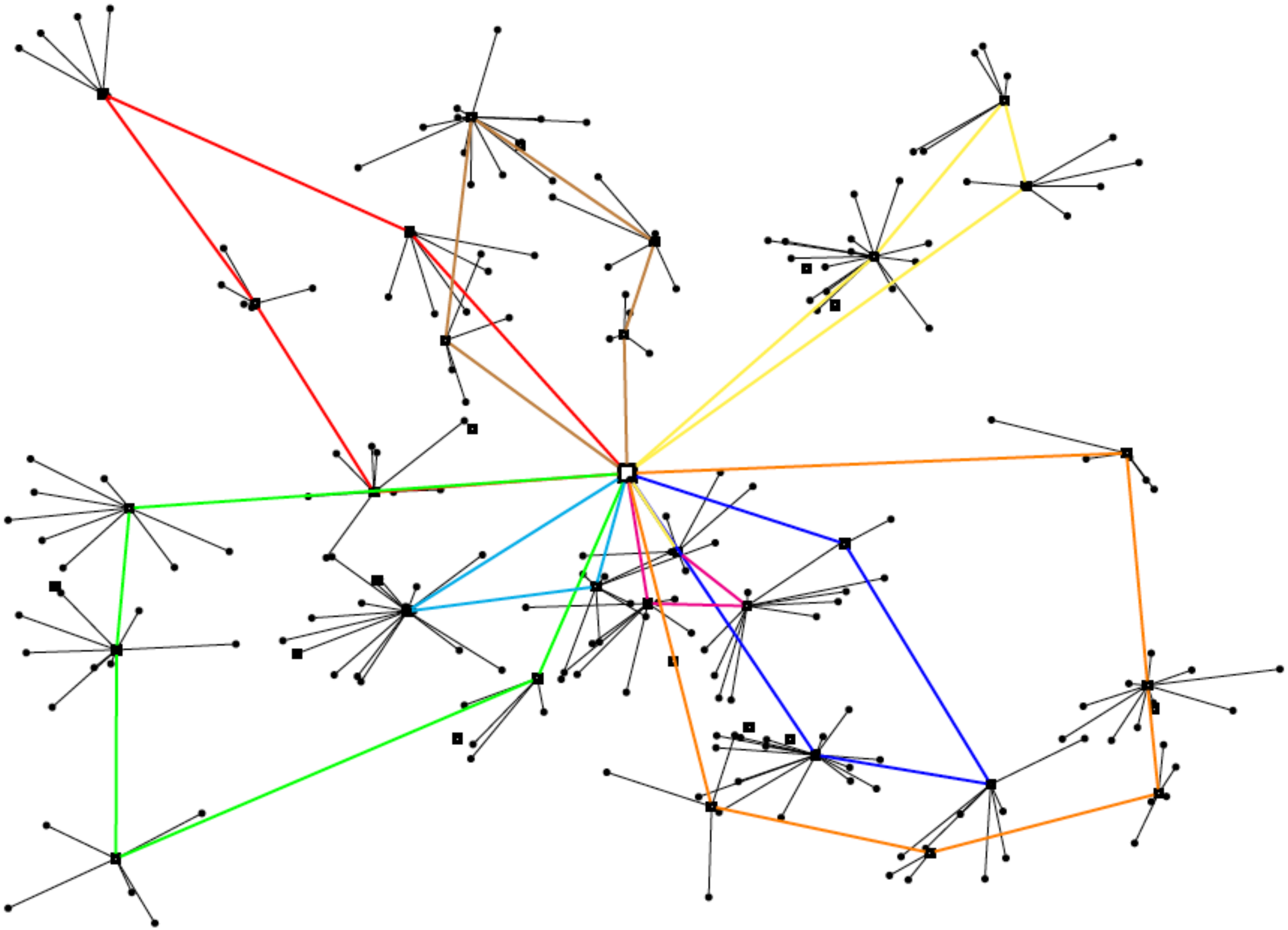
A Matheuristic for solving large-sized instances

- Iterated fashion → multiple solutions
- Construction phase (GRASP, stochastic)
  - Clark-Wright savings heuristic
  - $s_{ij} = c_{i0} + c_{0j} - c_{ij}$
  - Three selection types
- Improvement phase (VNS, deterministic)
  - Change two stops within one route
  - Change two stops between routes
  - Replace one stop
  - Add unvisited stops/remove visited stops
- Allocation of students to routes by exact method → Out-of-kilter method of Ford and Fulkerson [1]

[1] Ford and Fulkerson, *Solving the Transportation Problem*, Management Science , Vol 3 (1), 1956, pp 24-32

100 stops, 1’000 students



Matheuristics for VRP

- K. Doerner, V. Schmid, Survey: Matheuristics for rich vehicle routing problems, LNCS, 2010
- M. Ball, Heuristics based on mathematical programming, Surveys in Operations Research and Management Science, 2011
- L. Bertazzi, M.G. Speranza, Matheuristics for inventory routing problems, in 'Hybrid Algorithms…', Montoya-Torres et al (eds), 2012
- C. Archetti, M.G. Speranza, A survey on matheuristics for routing problems, submitted, 2014

…. still ad hoc algorithms

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Kernel search: A general heuristic approach to MILP problems

M. Grazia Speranza
Università degli Studi di Brescia

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Observations / starting points

- Often in an optimal solution there are few non-zero variables
- Often basic variables in the LP-relaxation are good predictors of non-zero variables in an optimal MILP solution
- Often reduced costs are good predictors of the likelihood of a non-basic variable to be non-zero in a MILP optimal solution

Kernel search

Basic concepts:

Kernel = set of 'promising' (likely to be non-zero) variables

MILPs restricted to **kernel and some more variables**

marginally wrong
(few variables missing)

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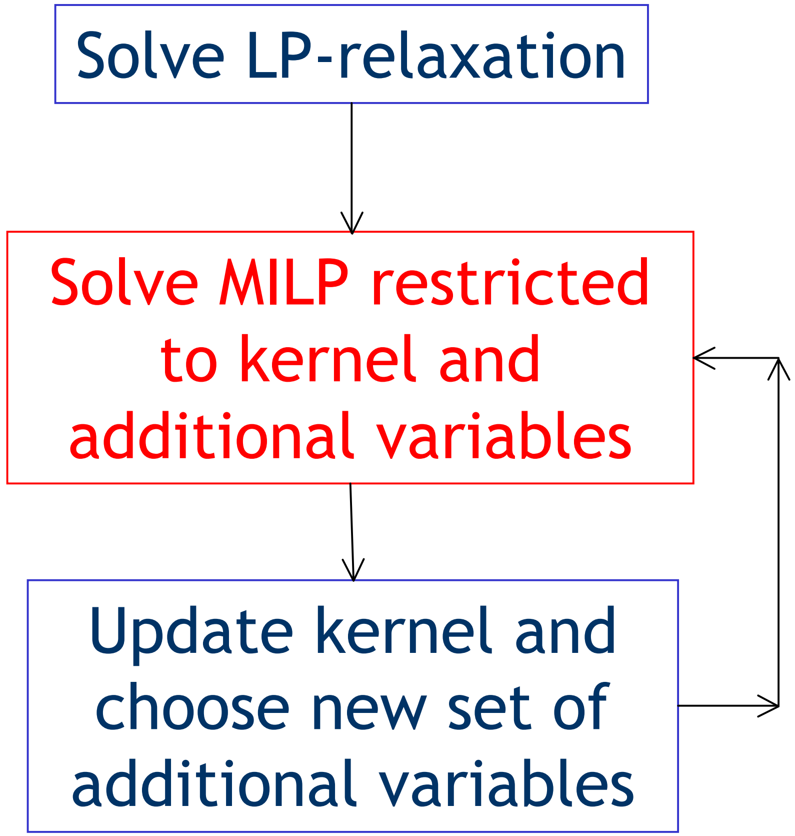
Kernel search – general scheme



Experience with Kernel Search

Portfolio optimization
Mansini, Speranza, EJOR (1999)
Angelelli, Mansini, Speranza, JCOA (2010)

Multi-dimensional Knapsack Problem
Angelelli, Mansini, Speranza, C&OR (2010)

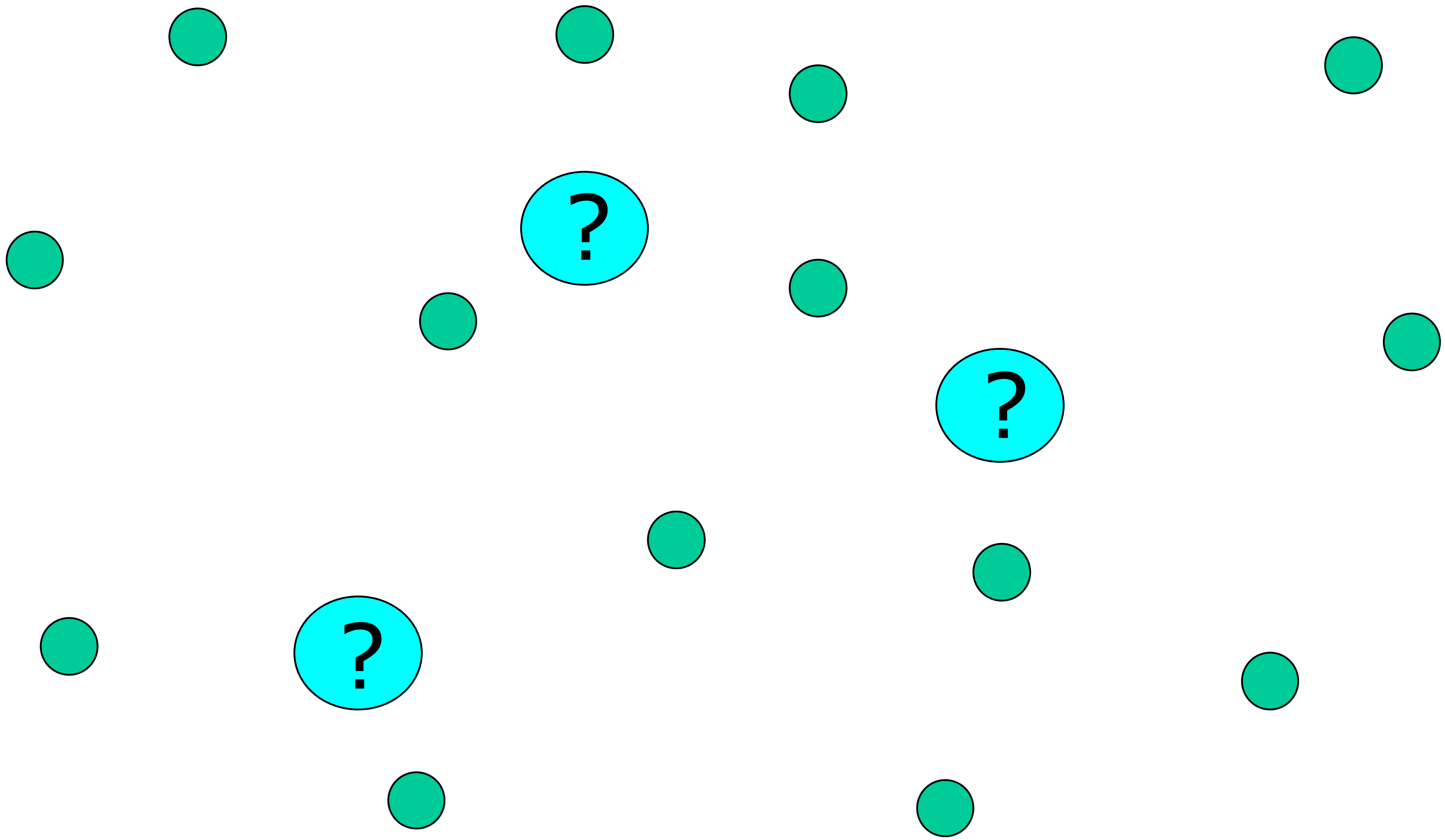
Index tracking
Guastaroba, Speranza, EJOR (2012)

Capacitated Facility Location Problem
Guastaroba, Speranza, JOH (2012)

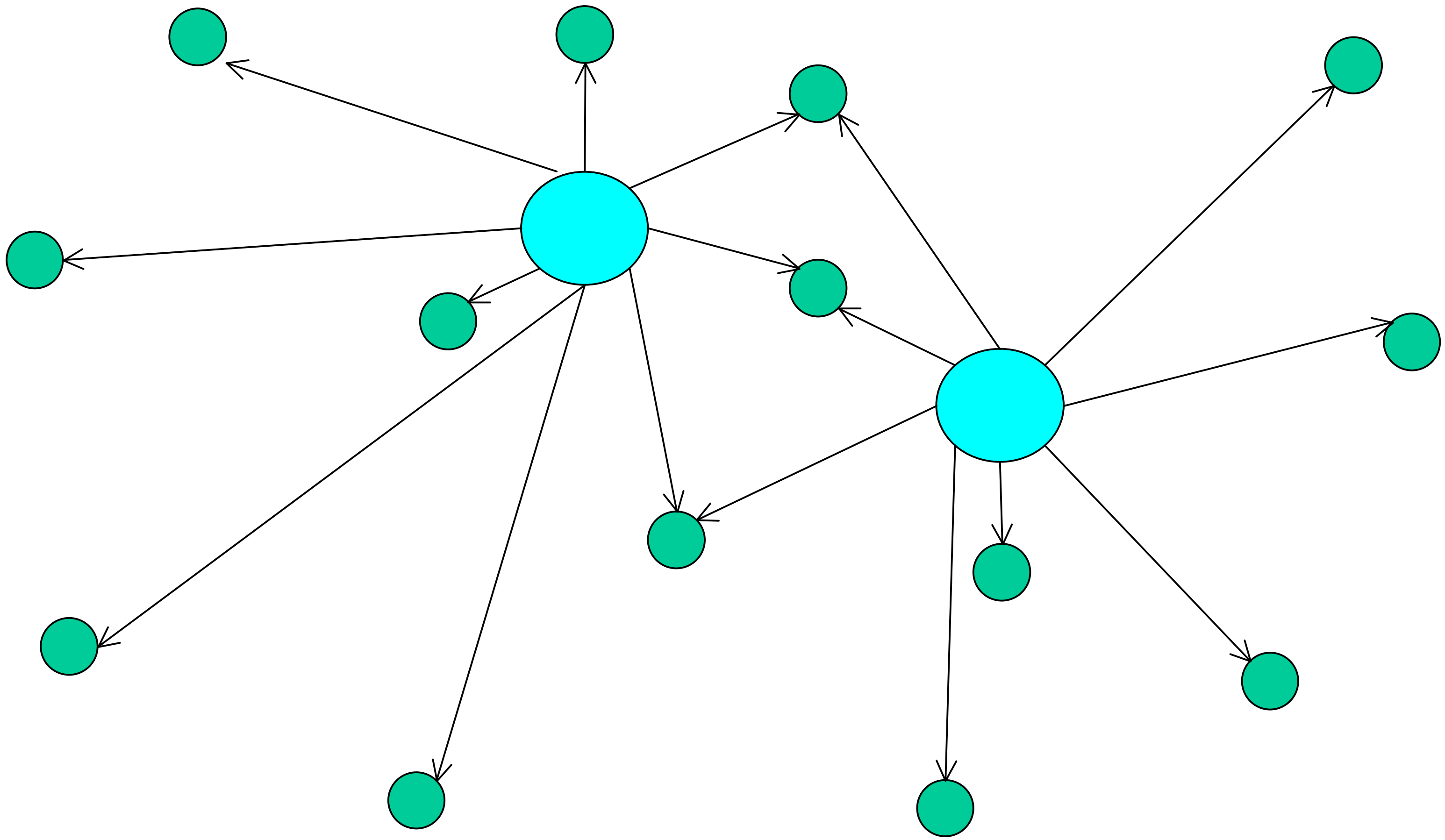
BILP problems (Single source CFLP)
Guastaroba, Speranza, EJOR (2014)

Bi-objective enhanced index tracking
Guastaroba, Filippi, Speranza, submitted (2014)

Capacitated Facility Location Problem



Capacitated Facility Location Problem



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Capacitated Facility Location Problem

$$\text{minimize} \quad z = \sum_{i \in I} \sum_{j \in J} c_{ij} x_{ij} + \sum_{j \in J} f_j y_j$$

$$s.t. \qquad \sum_{i \in I} x_{ij} \leq s_j y_j \quad j \in J$$

$$\sum_{j \in J} x_{ij} = d_i \quad i \in I$$

$$x_{ij} \leq d_i \quad i \in I, j \in J$$

$$x_{ij} \geq 0 \quad i \in I, j \in J$$

$$y_j \in \{0, 1\} \quad j \in J.$$

CFLP: Kernel search

- Kernel includes subsets of x for selected y
- A variable y can be removed from the kernel if not selected by p previous MILPs
- Only a subset of buckets is explored

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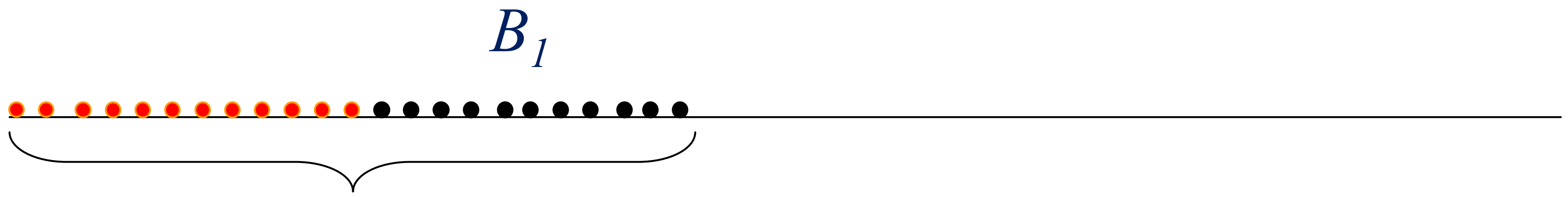
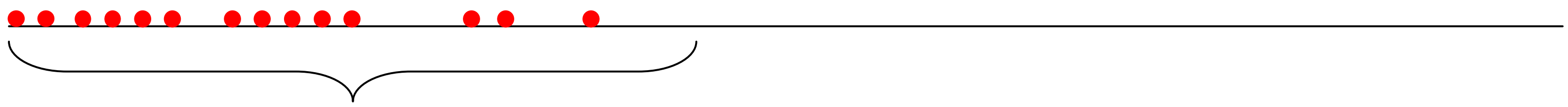
Kernel search – iterative phase



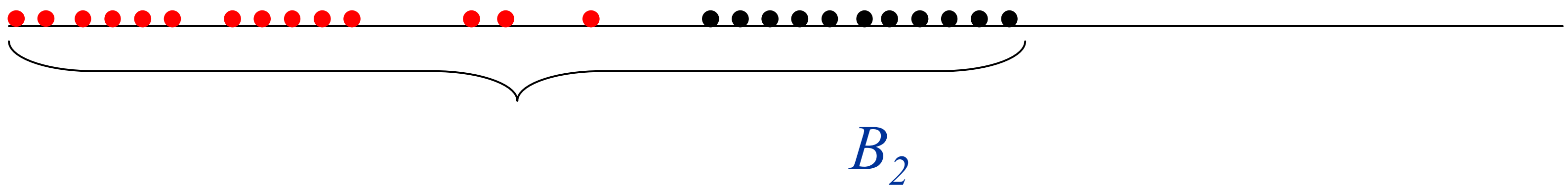
Restricted MILP

Kernel search – iterative phase



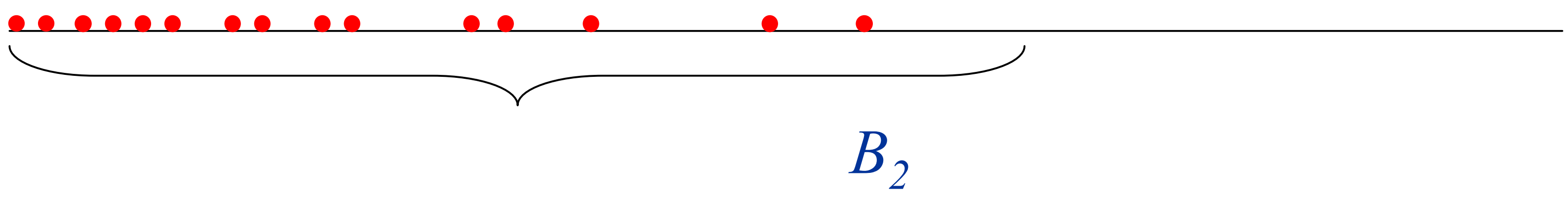
Updated kernel

Kernel search – iterative phase



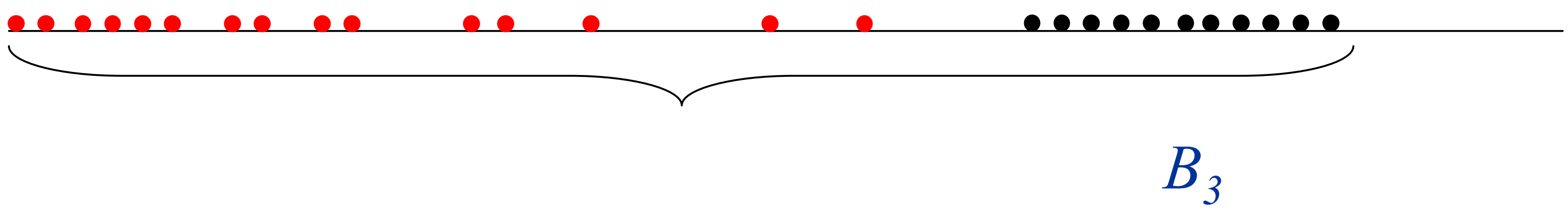
Restricted MILP

Kernel search – iterative phase



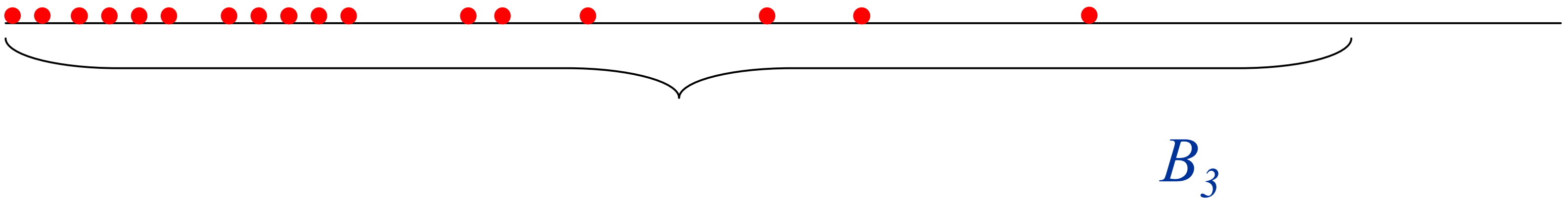
Updated kernel

Kernel search – iterative phase



Restricted MILP

Kernel search – iterative phase



Updated kernel

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CFLP: Instances

49 instances from the OR-library

Optimal solutions are known

100 instances from Avella and Boccia (2009)

Optimal solutions are known for 98 out of 100 instances

295 instances from Avella et al. (2009) Only heuristic solutions

- Test Bed A: 150 instances with fixed costs two orders of magnitude bigger than the other costs
- Test Bed B: 145 instances with fixed costs one order of magnitude bigger than the other costs

150 instances generated as in Avella et al. (2009) with fixed costs and other costs of the same order of magnitude (new instances)

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CFLP: A summary

- B-KS found the optimal solution 146 times out of 147
- B-KS improved best known solution for 275 instances out of 293
- Improvements: on average 0.425%, max 5.07%
- The few errors are very small (max 0.46%)

Kernel : conclusions

- Kernel search has been implemented in a straightforward way
- A general heuristic for MILP problems that performs better than available options is possible
- A general heuristic would increase the value of OR to practitioners (and to us)
- Ad hoc heuristics would remain valuable, like exact methods remain

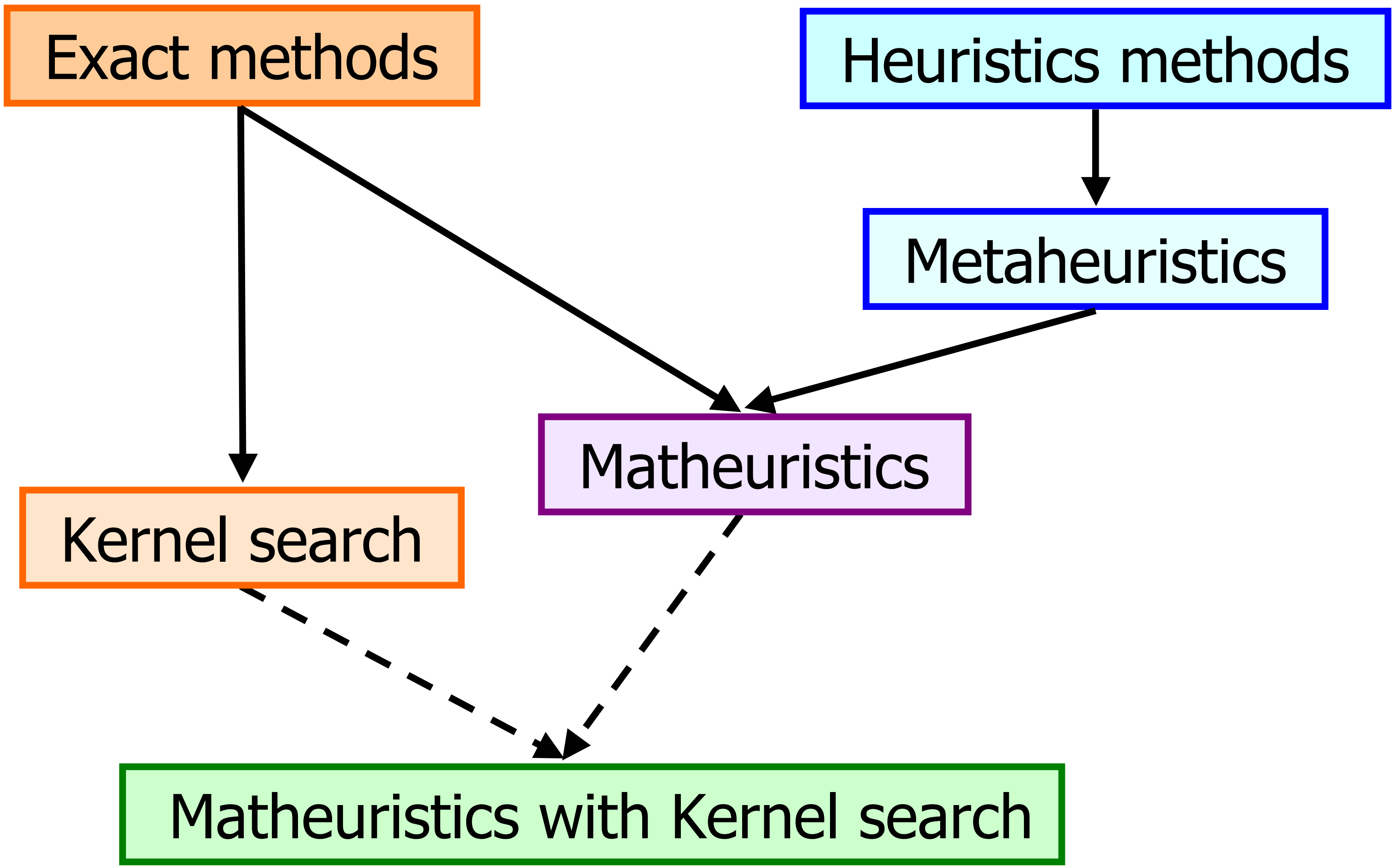
Integration vs optimality (3)

	Modeling	Solving
Optimality		
Integration		

Outline of the presentation

- [x] Integrated production management
- [x] Supply chain management
- [x] Exact methods
- [x] Meta-heuristic methods
- [x] Matheuristics
- [x] Kernel search
- [ ] Conclusion

Conclusion (1)



Conclusion (2)

Exact methods

Kernel search

Matheuristics

Metaheuristics

Heuristics methods

How to guide the search in direction of the optimum ?

Conclusion (3)

Better knowledge about the solution space !

Thanks a lot for your attention !

Questions ?