Part III - Case studies

Problems and Soft Constraints

Typical real problems include:

- Hard constraints (physical constraints)
- Preferably satisfied constraints (preferences, eg. deadlines)
- Uncertain constraints (errors, weathers. . .)

All such constraints $\Rightarrow$ unfeasibility
No such constraint $\Rightarrow$ many meaningless solutions

Usual approach: ad-hoc heuristic (but often efficient) handling.

RNA secondary structure prediction

RNA is a single strand molecule composed of A,U,G,C.

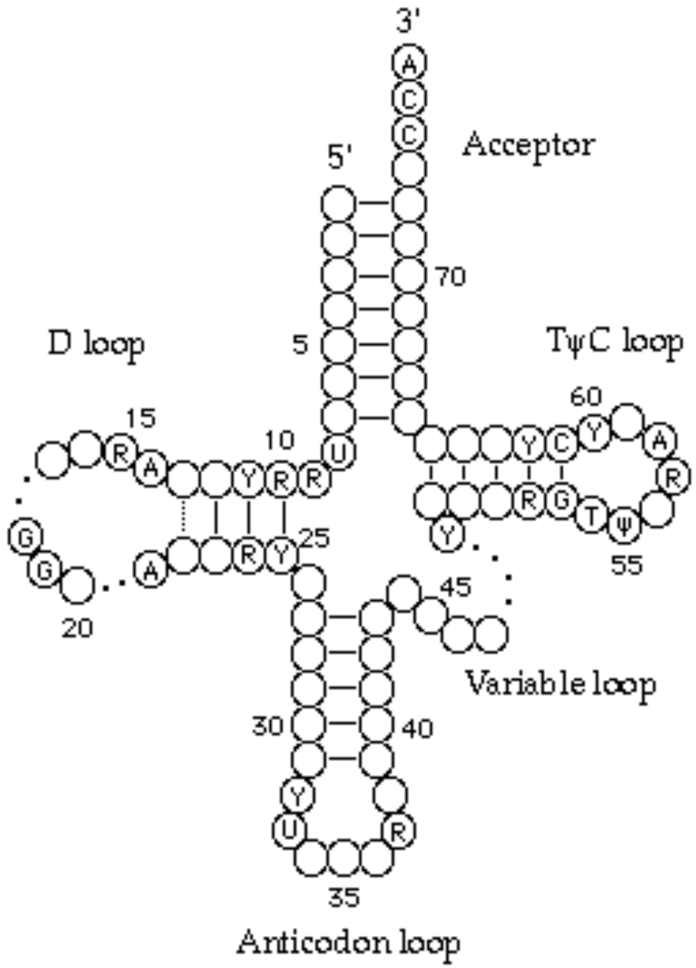
Functional RNA are structured (3d structure). Structure is related to function.

The structure is induced by base pairing: Watson-Crick (A-U,G-C) and Wobble (G-U).

Secondary structure: set of all Watson-Crick and Wobble base pairs.

Problem: determine the secondary structure of an RNA molecule from a single sequence.

A transfert RNA



RNA secondary structure prediction

Other sources of information:

- thermodynamics.
  Zuker's algorithm: DP algorithm that finds an optimal secondary structure. Pb: thermodynamics is not precise enough.

  McCaskill matrix: given an RNA sequence, computes the probability that a given base is paired to another given base (based on thermodynamics).
- biological knowledge: one may know/test that a given base is paired or not, is paired to a given other base.

A CSP model (C. Gaspin, 1995)

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For a sequence of length $n = (b_1, \ldots b_n)$:

- one variable x_i per base
- domains: $d_i = \{1, \ldots, n\}$. $b_i = i$ means b_i unpaired.
- constraints: Watson-Crick/Wobble only.

  $x_i = j \Leftrightarrow x_j = i$

  No pseudo-knot: for $i < j, k < l, (j, l)$ is forbidden for x_i, x_k if $i < k < j < l$ or $k < i < l < j$.

  Many other constraints. . .

  Experimental knowledge: a base is unpaired, is paired, with a specific base...

Usually too many solutions. Need more information.

Exploiting thermodynamics

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McCaskill matrix $P(i,j)$ probability that b_i is paired with b_j.

For algorithmic reasons (satisfaction problem):

- fix a threshold p.
- forbid all pairs $b_i = j$ such that $P(i,j) < p$.

Poor handling of probabilities, Choice of $p\ldots$

Enforce arc consistency, then solve as a Max-CSP with unary soft constraints (maximize the number of paired bases) using a maximal clique tree-search algorithm.

Satellite scheduling

- var/dom: a set S of pictures. Each picture can be taken at different time points.
- binary constraints: only three instruments are available and each picture requires some instruments with possible transition times for reconfiguration.
- ternary constraints: the data bus bandwidth is limited.
- global constraint: the local memory is limited.

Overconstrained: instanciate a subset of S which maximizes the sum of the weights of the pictures (and satisfies all constraints).

RDS (no global constraint)

CP'01

val = # of pictures, $*$ = optimality proof (within 30')

pb	n	e	FC	(cpu ")	RDS	(cpu ")
404	100	610	48	1800	49*	0.5
408	199	2032	3076	1800	3082*	14
412	300	4048	15078	1800	16102*	29
414	364	9744	21096	1800	22120*	86
503	105	403	8095	1800	9096*	2.5
505	240	2002	12088	1800	13100*	15
507	311	5421	12110	1800	15137*	55
509	348	8276	19104	1800	19125*	106

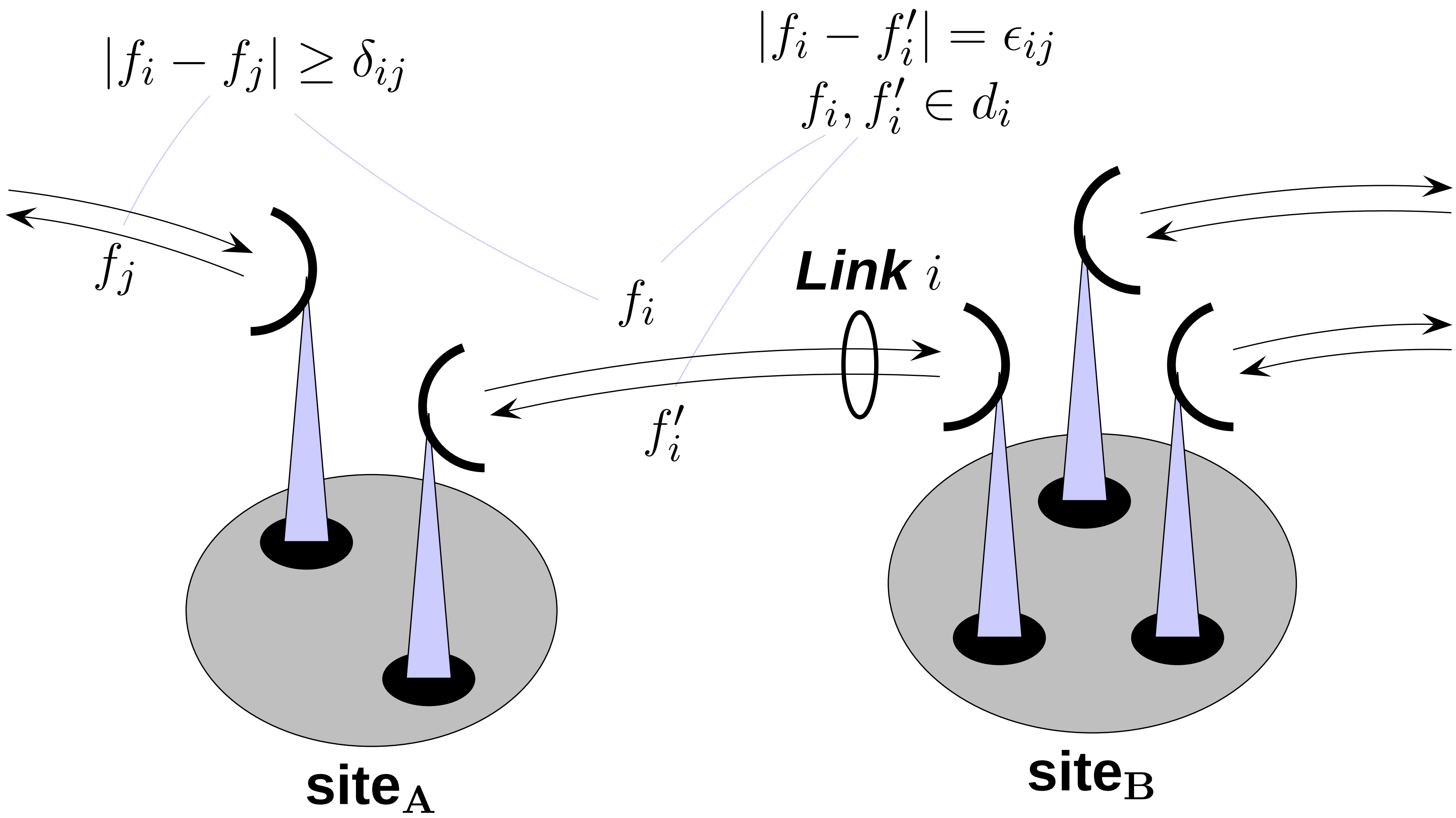
Satellite scheduling

Beyond RDS, these instances have been tackled by several approaches:

- local search: taboo search (M. Vasquez).
- LP + column generation: to provide global lower bounds
- 0/1 LP: as a multidimensional Knapsack (MKP01), to provide global lower bounds (M. Vasquez).

The MKP01 model is solved to optimality by CPLEX 7.0 (with float tolerance problems) on most instances (including the global constraint). Cpu-time may reach 5.10^4 sec. on a modern Pentium machine.

Frequency assignment (CELAR)



FAP - criteria

- minimize the maximum frequency used (possibilistic CSP)
- minimize the number of frequencies used (optimisation/global soft constraint)
- minimize the weighted constraint violation (Max-CSP)

Several instances available: from 200 to 916 vars, from 1200 to more than 5000 binary constraints. Domains usually have more than 30 values.

FAP: results

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Tackled in the CALMA project (1994) and then by individuals. Most problems solved to optimality...

Max-CSP problems are very hard (even for local search). No proof of optimality after CALMA.

- 1997: graph decomposition + RDS proved optimality of Celar06 $(5.10^6$ sec., Sparc 5). PFC-MRDAC (2.610^5 sec, Sparc 2).
- 1999: preprocessing ($\approx$ soft AC) + dynamic programming ($\approx$ bucket elimination) + a lot more: solves most instances to optimality (Arie Koster, PhD thesis).

Conclusion

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Soft constraint technology is still in its enfancy.
There is much to do:

- use existing frameworks to build more realistic models for existing problems, that may exploit recent algorithms (eg. bucket elimination, PFC-MRDAC. . .)
- improve algorithms for solving existing models in existing frameworks:
  - stronger preprocessing
  - global soft constraints
  - combination of bucket elimination, branching and local consistency or other preprocessing.

Existing implementations (we know...)

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- Con'Flex: Conjunctive fuzzy CSP system with integer, symbolic and numerical constraints (www.inra.fr/bia/T/conflex).
- clp(FD,S): semi-ring CLP. (pauillac.inria.fr/~georget/clp_fds/clp_fds.html).
- LVCSP: Common-Lisp library for Valued CSP with an emphasis on strictly monotonic operators (ftp.cert.fr/pub/lemaitre/LVCSP).
- Choco: a claire library for CSP. Existing layers above Choco implements Weighted Max-CSP algorithms (part of LVCSP, (www.choco-constraints.net).

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