The chemical reaction: an effective metaphor

La réaction chimique: une métaphore opérante

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PLAN

1. Early days: Gamma
2. Exploring the metaphor in various directions
3. The value of metaphors

Gamma in a nutshell

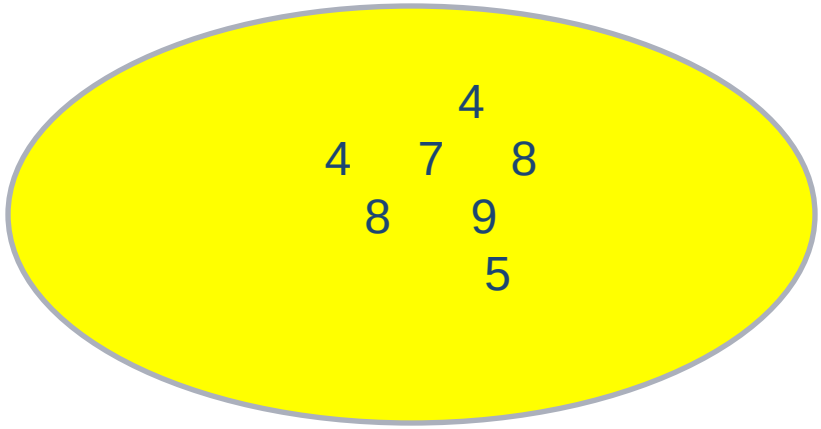
Basic ingredients:

- A solution containing atomic values
- Conditional reaction rules:

  replace $a_1,\ldots, a_n$ by $b_1,\ldots, b_m$ if $C(a_1,\ldots, a_n)$
- Purely local computation steps
- Result: inert solution

Basic example

Maximum: replace a_1,a_2 by a_1 if $a_1 \geq a_2$



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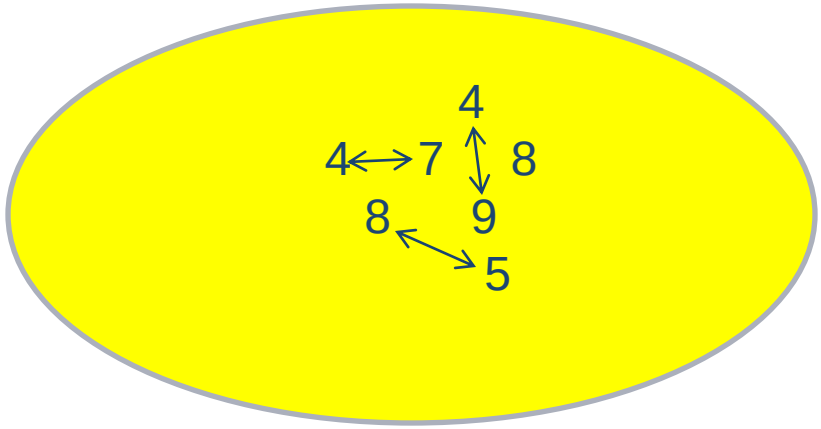

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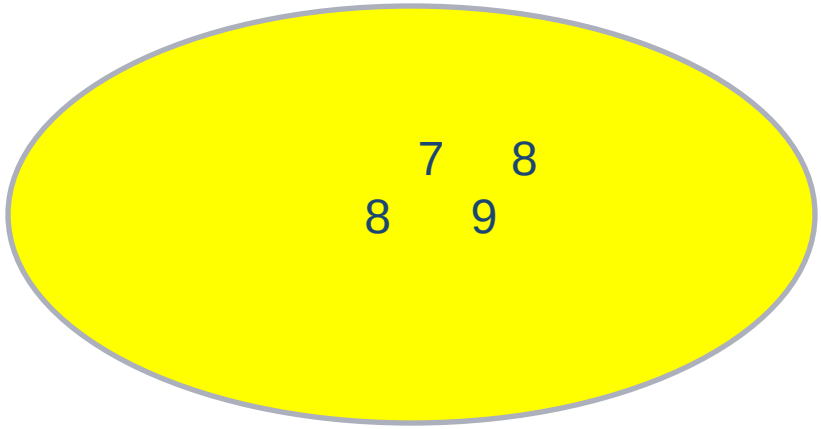

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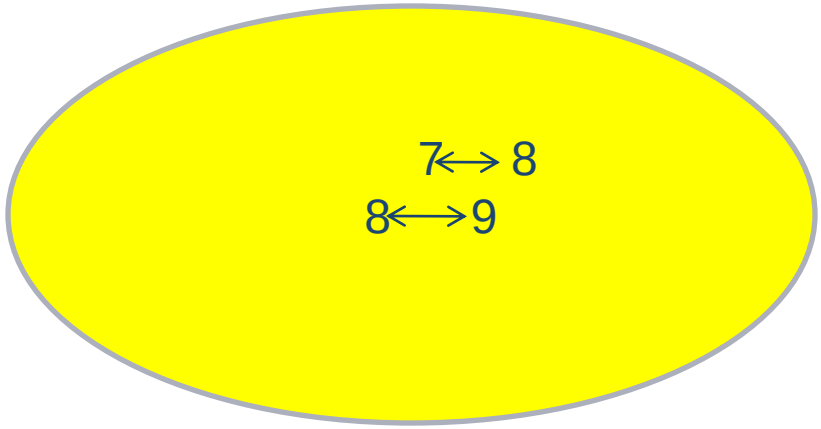

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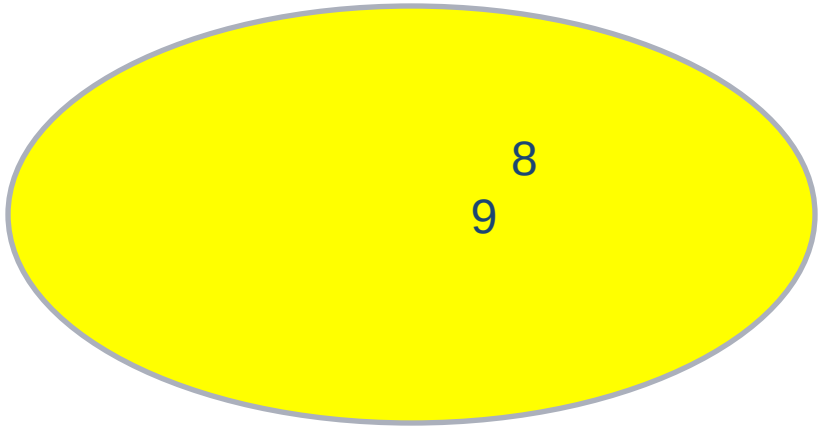

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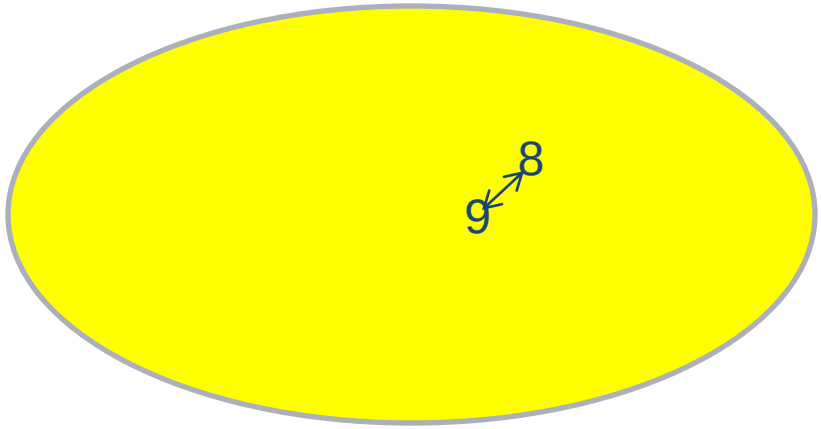

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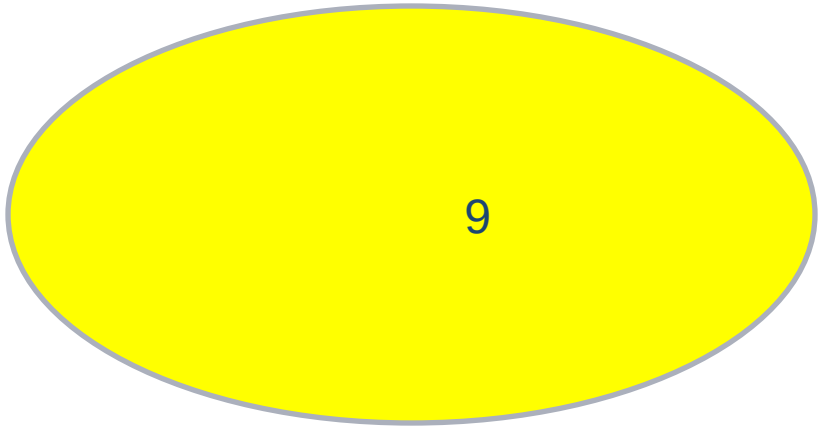

Other basic examples

- Sorting:

  replace $(i_1,a_1), (i_2,a_2)$ by $(i_1,a_2), (i_2,a_1)$ if $i_1 \geq i_2 \wedge a_1 < a_2$

- Eratosthenes' sieve:

  replace (a,b) by (a, a+b/2), (a+1+b/2,b) if b > a+1

  replace (a,b) by a if a = b

  replace a, b by a if div(a,b)

Motivation

Observation: existing programming models lead to overspecify execution control

Detrimental with respect to

- Program verification: need to cope with unrelevant details
- Exploitation of the features of parallel architectures : need to uncover parallelism from a sequential program

Objective: get rid of unnecessary sequentiality

Illustration

Sorting:

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Correctness proof for free:

- Inert solution $\Rightarrow$ elements are well sorted
- Local invariant $\Rightarrow$ the result is a permutation of the initial sequence

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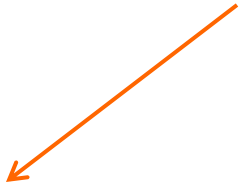

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Exploring the metaphor (1/2)

- Applications (image processing, graph processing, OS kernel, self-organizing systems, service orchestration, etc.)
- Expressing various computation models and languages (Petri nets, Kahn process networks, Linda, etc.)
- Implementations (Maspar, Intel iPSC2, Connexion Machine, PRL-DEC Perle 1, etc.)
- Program derivation and verification (security protocols, shared virtual memory coherence protocols, etc.)

Exploring the metaphor (2/2)

- Richer language (types, combinators, etc.)
- Higher-order versions : chemical abstract machine, higher-order Gamma, the γ-Calculus, HOCL, etc.
- Hybridization with other models and metaphors (Gammalög, λLO, MGS)
- Unexpected directions (software architectures, shape types)

The γ-calculus

$M = x \mid \gamma\,\langle x\rangle.M \mid M_1, M_2 \mid \langle M\rangle$

$(\gamma\,\langle x\rangle.M), \langle N\rangle \rightarrow M\,[N/x]$ if inert(N)

$M_1, M_2 \equiv M_2, M_1$

$(M_1, M_2), M_3 \equiv M_1, (M_2, M_3)$

The γ-calculus

$(\gamma\ \langle x\rangle.\ \gamma\ \langle y\rangle.x)\ ,\ \langle A\rangle, \langle B\rangle$

↓

$(\gamma\ \langle y\rangle.\ A), \langle B\rangle$

↓

A

$\equiv$

$(\gamma\ \langle x\rangle.\ \gamma\ \langle y\rangle.x)\ ,\ \langle B\rangle, \langle A\rangle$

↓

$(\gamma\ \langle y\rangle.\ B), \langle A\rangle$

↓

B

PLAN

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2. Evolutions, extensions and varied applications
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Some lessons

- The choice of a metaphor can have a dramatic impact on a computational model (reasoning, design, implementation,...)
- Language design: Keep it simple ! (KISS principle, Occam's razor)
- Inherently distributed computational models are still topical (cloud computing, service oriented architectures, multicore architectures, etc.)

Metaphors in computer science

- Countless examples of metaphorical terms: stack, object, package, instruction, pipe, queue, jump, flow, call, message, thread, exception, throw/catch, menu, recycling bin, …
- Criticisms from computer scientists:

  “By means of metaphors and analogies, we try to link the new to the old, the novel to the familiar. Under sufficiently slow and gradual change, it works reasonably well; in the case of a sharp discontinuity, however, the method breaks down.... “

  E. Dijkstra

Metaphors in philosophy of science

Two extreme positions:

Max Black:

- Scientific explanations should rely only on laws, deductive relations, logical generalizations, ...
- Theories should avoid the vagueness and ambiguities of ordinary language, metaphors can hide the truth
- “Thou shalt not commit metaphor!”

Douglas Berggren:

- “Any scientific explanation, though ostensively a logical deduction, can nonetheless rely on a metaphor.”
- Theories need concepts from ordinary language.

Metaphors in computer science

Very different types of use and impact:

- Human Computer Interfaces: desktop, menu, button, recycling bin,…
- Design metaphors: procedure, folder, package, …
- Paradigm shifts: object-oriented computing, data flow languages, chemical reaction, DNA computing, quantum computing, PPSN …

"Because computer science is a science that creates its own subject matter, successful metaphors are used , not to describe the way things are, but the way things should be." (T.R. Colburn, G.M. Shute)

Further metaphors

- A lot of interest in different types of metaphors: chemistry, DNA computing, quantum computing, PPSN …
- Beyond metaphors in « hard sciences » inspiration can also be taken from social sciences
- Specially useful when many new applications are « user-centric » and have a significant social or legal dimension
- Two examples:
  - Control (over data, computation,…): key issue in privacy, for business models
  - Logical causality: key issue for liability, dependable computing

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