What is Wrong with Process Calculi – And How to Recover ?

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Glory and misery of process calculi

Achievements of process calculi

- A fruitful theory for modeling concurrent systems
  - the proper way of expressing concurrency
  - early detection of design mistakes
- Famous calculi: CSP, CCS, ACP…
- ISO standards: LOTOS, E-LOTOS
- Turing awards: Hoare, Milner
- Robust tools: CADP, FDR, mCRL2, PAT…

  with many successes on industrial case studies
- Conferences: CONCUR, EXPRESS/SOS …
- Process algebra handbook (1342 pages)

But a shrinking audience...

- No longer a research priority for funding agencies
- Fewer industrial users:
  - industry still has many problems with concurrency
  - but concurrency theory is not seen as THE solution
- Fewer students:
  - no clear demand for learning concurrency theory
  - difficult to create (or even maintain) such courses
- Negative feedback loop:
  - fewer students $\Rightarrow$ fewer tools $\Rightarrow$ fewer aplications $\Rightarrow$ ...
- Concurrency experts are progressively retiring

A declining influence (1/2)

- Java (1995)
  - parallelism based on shared variables and locks
  - no formal semantics – Java memory model issues
  - back in time to the 1970s (pre-Hoarian era)
- UML (1997)
  - concurrent state machines with a graphical syntax
  - no formal semantics – incompatible views
- DSMLs (*Domain-Specific Modelling Languages*)
  - XML-based syntax
  - semantics in natural language (with OCL constraints)

A declining influence (2/2)

- Ocaml 5 (2023)
  - formely, JoCaml (2014) was based on the join-calculus
  - instead, Ocaml 5 brings shared-memory concurrency

- A modern Cassandra complex:
  - we know everything about concurrency, in full detail
  - but no one pays attention to our opinion

A few sharp statements

"Process algebra has lost the battle!"

Moshe Vardi (May 2020)

"Almost no one uses process calculi anymore these days."

Joost-Pieter Katoen (April 2023)

Why such a decline?

Many reasons, in combination

- Concurrency theory is inherently difficult
  - but we make it more obscure (Greek letters…)
- Concurrency theory is intrinsically diverse
  - but we encourage artificial proliferation
  - do we need hundreds of bisimulations?
  - do we need a different formalism in each university?
- Outsiders cannot distinguish key ideas from details
- Lack of critical mass, insufficient tool support
- Few solutions directly usable by practitioners

Error #1: Over-emphasis on "calculi"

- CSP (1978) was a programming language
- CCS (1980) was a "calculus"
  - elegant definition, with a syntax that fits on one line
  - but too simple for practical needs
  - few realistic systems have been modelled using CCS
- "calculi" ≠ "languages"
  - calculi focus on semantics, and ignore anything else
  - calculi must be extended, often in incompatible ways
  - they do not support good engineering practices
  - they do not care about developer productivity

Error #2: Purely functional style

- Originally, CSP (1978) was an imperative language
- But CCS (TCSP, LOTOS...) chose a functional style
- PRO:
  - CCS's formal semantics was state-of-the-art at its time
- CONS:
  - no loop operator, only recursive processes
  - no mutable variables, only parameters
  - parameter lists may become long and error-prone
  - imperative style combined with static analysis is as safe as functional style, and much more flexible

Error #3: Algebraic style (1/3)

- Trend to use algebra everywhere:
  - 1) for data types and functions: LOTOS, PSF, μCRL, etc.
  - 2) for processes: PSF, μCRL, mCRL2
- PRO 1 (for data types and functions):
  - abstract data types were fashionable in the 80s
  - formal semantics, independent from implementations
  - evaluation of expressions is free from side effects
- CONS 1:
  - completeness and confluence (nondeterminism) issues
  - no proper modelling of exceptions
  - "*ADTs really killed LOTOS.*" Juan Quemada (E-LOTOS editor)

Error #3: Algebraic style (2/3)

- PRO 2 (for processes):
  - appealing (?) analogy with arithmetics: 0, 1, +, .
  - a few intuitive axioms: commutativity, associativity...
  - binary sequential composition (>> CCS's action prefix)
- CONS 2:
  - poorly readable
  - overloading: "+" means either addition or choice
  - LISP-like parentheses: "))))" mixing data and processes
  - insufficient expression of data flow, e.g.,
    sum x.(RECV (x).SEND (x)) instead of RECV ?x; SEND !x

Error #3: Algebraic style (3/3)

- Also:
  - software/hardware engineers are not mathematicians
    $\Rightarrow$ algebra is not so appealing to them
  - algebraic specifications are harder to implement efficiently than, e.g., finite-state machines
  - algebraic laws (but congruence) do not help much in formal verification, done by state-space exploration

- All in one, algebra brings more problems than solutions

How to recover?

Back to the roots

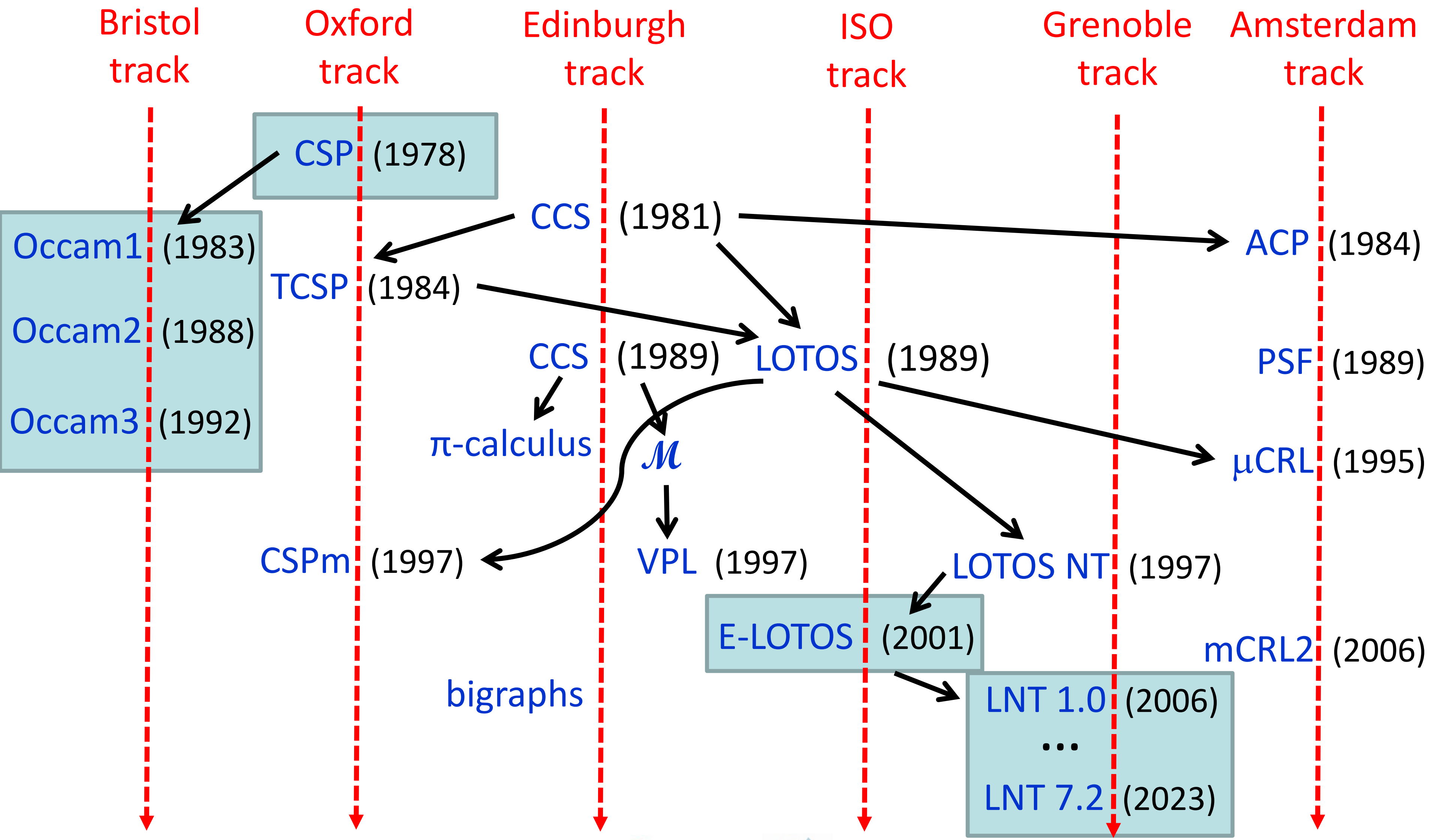
What is really essential in process calculi?

1. An effective way to precisely model concurrency
2. Message-passing communication
3. Action-based semantics (transitions, not states)
4. Formal semantics given by SOS rules
5. Algebraic properties:
   - commutativity, associativity, etc. of operators
   - congruence of parallel composition for bisimulation (to fight state-space explosion)

Guidelines for a better language

- Stay away from calculi
  - a one-line language like CCS is not sufficient in real life
- Stay away from the fully functional style
  - mainstream programming languages are imperative
  - but functional traits (e.g. pattern matching) are ok
- Stay away from fully algebraic approaches
  - most programmers are not mathematicians
  - reuse the advances of structured programming
- Retrospectively, CSP-1978 was very well done

Global map of process calculi



A few words on LNT

- LNT: language being developed at INRIA Grenoble
  - inspired from CSP-1978, Occam, and E-LOTOS
  - process calculus with imperative and functional traits
  - formal semantics given by SOS rules
  - strong typing and static analyses to detect mistakes
  - support for proofs: assertions, pre- / post-conditions
- Language primarily designed for engineers:
  - keep things as simple as possible
  - use notations as standard as possible (Ada-like syntax)
  - emphasize readability by non-experts

A few results about LNT

- Tool chain for LNT:
  - two compilers (LNT2LOTOS and TRAIAN) – 90,000 locs
  - 80% of these compilers written in LNT ("self-hosted")

    LNT is both a specification and programming language
  - part of the CADP toolbox (https://cadp.inria.fr)
- On-going dissemination:
  - engineering and master courses (easier than LOTOS!)
  - 28 published case studies done with LNT:
    e.g. Google, Nokia, Orange, STMicroelectronics, Tiempo
  - 14 research tools generating LNT code

Conclusion

Concurrency theory today

- The audience of concurrency theory is shrinking
  - its valuable results might fade to oblivion
- Time has come for encyclopedic synthesis:
  - reexamine / select / simplify / sort
  - tutorials needed ("*Concurrency for the dummies*")
  - contributions to Wikipedia
- Strengthen the links of concurrency theory with:
  - industrial applications
  - other branches of computer science

Process calculi have a future

- There are still industrial needs:
  - concurrent systems everywhere: hardware, software
  - safety, security, performance issues
- Other languages are not that good:
  - limited expressiveness/scalability, dubious semantics
  - absence of sound verification tools
- Merge process calculi with more general languages
  - extend the scope and applicability of process calculi
  - use them as target languages to implement DSMLs