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CPF: The Certification Problem Format

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  - standard input format beneficial (DIMACS, TPTP, TPDB, . . .)

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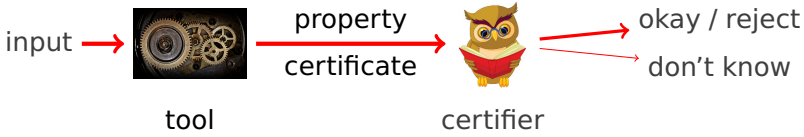

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- certification: verify output of untrusted tools
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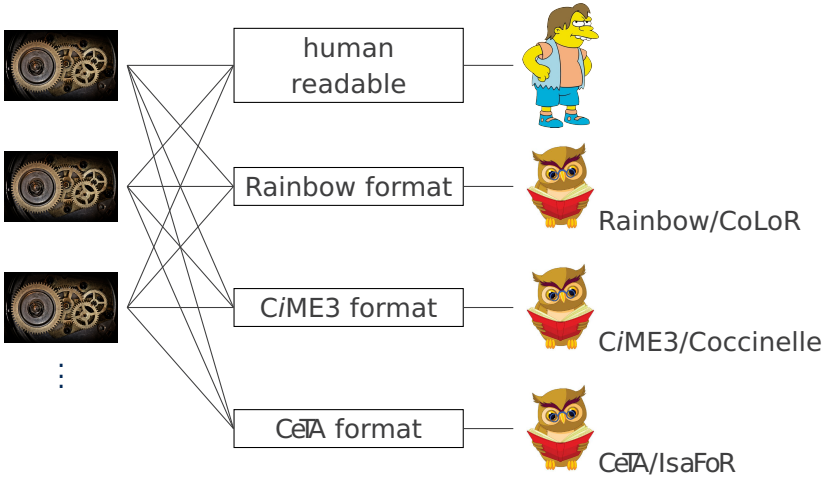
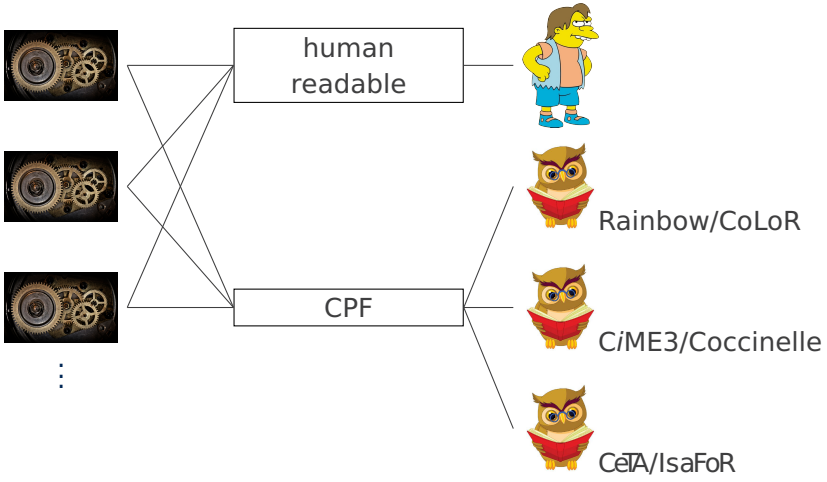
  - requires certificates
- restriction of certificate format in this talk
  - fixed set of languages (term rewrite systems, integer transition systems)
  - fixed set of properties (termination, complexity, safety, . . .)
  - fixed set of supported techniques

Situation before CPF: Multiple Formats for Certificates



Using the Certification Problem Format



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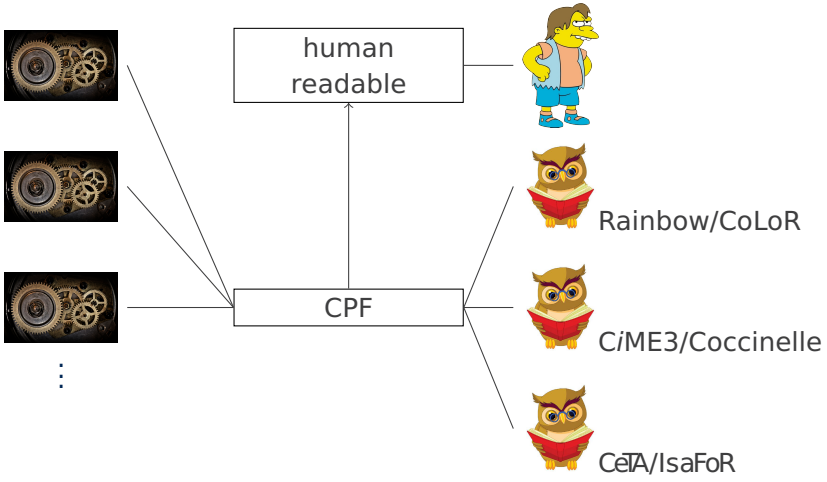

Advantages of Certification Problem Format

- tools only have to support up to 2 output formats

$\Rightarrow$ certifiers are more likely to get input

- new certifiers can be based on CPF

$\Rightarrow$ no need to convince tool authors to support just another output format

- CPF can be used as “input problem” for certifiers

$\Rightarrow$ gather database of CPFs

History of CPF

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- since 2012: used in confluence competition
- since then, addition of several new input formats and properties
  - variants of rewriting, several properties
  - integer transition systems (termination and safety)
  - on its way: simplified LLVM (termination)

Design Choice: XML

- CPF generation supported by various tools
  - termination (AProVE, ConCon, CiME3, Matchbox, NaTT, TTT2, Microsoft T2)
  - confluence (ACP, CSI)
  - complexity (AProVE, CaT, TCT)
  - completion (mkbTT, KBCV)
  - safety (Microsoft T2)
- characteristics
  - small number of proofs steps (in comparison to SAT/SMT)
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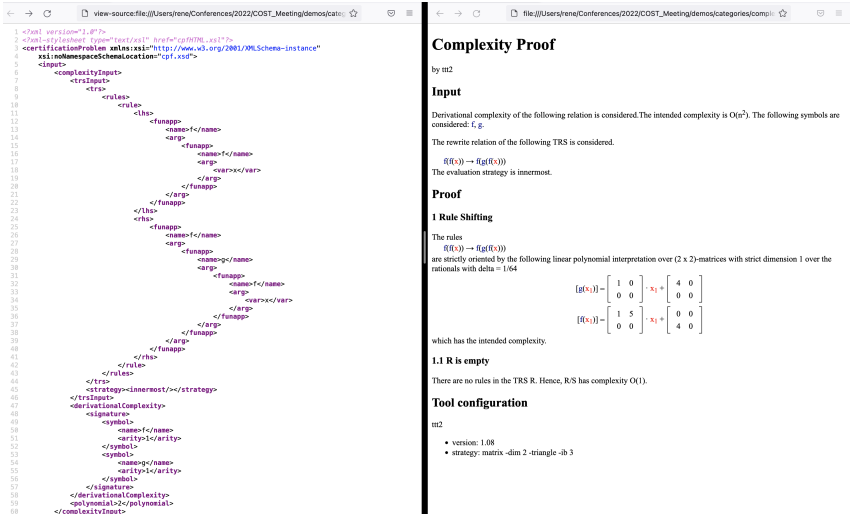
  - new proof techniques frequently arise
- consequences: use XML
  - XML overhead does not harm
  - easy to produce and display via XML-libraries
  - easy to extend CPF by new definitions

Example Complexity Proof: Source and Pretty-Printed



Design Choice: Certifier-Friendly

- CPF created by representatives of certifiers
  by merging preliminary formats of certifiers

$\Rightarrow$ CPF is certifier-friendly
  - complete proof tree has to be given
  - some certifier needs information $\Rightarrow$ CPF demands it
    (prefer verbose certificates over complicated reconstruction)
  - still CPF is easy to generate

```
<dpProof>
  <redPairUrProc>
    <redPair> ... </redPair>
    <usableRules> ... </usableRules> <!-- convenience -->
    <dpProof> ... </dpProof>
  </redPairUrProc>
</dpProof>
```

Design Choice: Determinism

- several variants of same technique
  - naming scheme of variables, new symbols, . . .
  - approximation of well-founded orders
  - . . .

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- several variants of same technique
  - naming scheme of variables, new symbols, . . .
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  - . . .
- specifying each possible variant is cumbersome
  (would require formalization of all variants)
- solution: leave variants unspecified, provide result in output

Example: Reduction Pair Processor

Theorem (Rule Removal)

if $(\succsim, \succ)$ *is reduction pair and* $\mathcal{P} \cup \mathcal{U}(\mathcal{P}, \mathcal{R}) \subseteq \succsim$ *then* $SN(\mathcal{P} \setminus \succ, \mathcal{R}) \implies SN(\mathcal{P}, \mathcal{R})$

- problem: $\succ$ usually only approximated

$\Rightarrow$ $\mathcal{P} \setminus \succ$ depends on approximation

```
<dpProof>
  <redPairUrProc>
    <redPair> ... </redPair>
    <usableRules> ... </usableRules>
    <dps> ... </dps>          <!-- remaining pairs -->
    <dpProof> ... </dpProof>
  </redPairUrProc>
</dpProof>
```

Significance of Determinism

Key issue: identify wrong proof steps at right position

- wrong termination proof (in first step it was not allowed to delete pair 2)

$$(\{1,2,3\},\mathcal{R}) \overset{\textit{redpair}}{\hookrightarrow} (\{3\},\mathcal{R}) \overset{\textit{depgraph}}{\hookrightarrow} \textit{done}$$

- certifying proof without determinism

$$(\{1,2,3\},\mathcal{R}) \overset{\textit{redpair}}{\hookrightarrow} (\{2,3\},\mathcal{R}) \overset{\textit{depgraph}}{\hookrightarrow} \textit{not done}$$

- certifying proof with determinism

$$(\{1,2,3\},\mathcal{R}) \overset{\textit{redpair},\{3\}}{\hookrightarrow} \textit{not allowed to switch to } (\{3\},\mathcal{R})$$

Extensions and Changes of CPF

- extensions
  - CPF was extended regularly (new definitions / techniques / properties)
  - since 2016: discussion in community via CPF mailing list
  - from 2016: discussion between CeTA-team and tool authors
  - problem: some certifiers that supported CPF initially are no longer developed
- changes
  - are tried to be avoided (backward compatibility)
  - sometimes beneficial (fix design bugs, unify elements, . . .)
  - so far only happened twice (CPF 1.x to 2.0, 2.0 to 2.1), converters available

Conclusion

- CPF
  - proof format with fixed set of properties and techniques
  - used in two annual competitions (currently checked by CeTA certifier)
  - supported by several tools
- benefits in two directions
  - certifiers: get inputs from various tools
  - tools: generated proofs get checked on validity
- availability of CPF
  - `http://cl-informatik.uibk.ac.at/software/cpf/` (old: dedicated website)
  - `http://cl-informatik.uibk.ac.at/software/ceta/` (new: part of CeTA)
- problems
  - only one actively maintained certifier (?)
  - limited expressivity, not generic $\Rightarrow$ interesting for WG3?