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Resource-aware programming ...

or what can we learn from Meltdown and Spectre

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Remember these Guys . . .

[1] Editor’s Letter, CACM Vol. 61, No. 9

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High-Level Analysis[1]

Because Spectre and Meltdown exploit the performance visibility of speculative actions to create information side channels, they extend the functional specification of the architecture to include its detailed performance.

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[M]aking strong assurances of application security on a computing system requires detailed performance information.

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Resource as First-Order Citizens

Example

```
/*
sorting of a list |l| using |compare| as a comparison function
*/
sort :: (l: list A) -> (compare: A -> A -> bool) -> list A

|assuming|
   the number of elements of |l| is bounded by |n|
   the size of the elements of |l| is bounded by |m|
|then|
   the number of elements of the result is bounded by |n|
   the size of the elements of the result is bounded by |m|
   the number of calls to |compare| is bounded by |n * log (n)|
   the size of both arguments in all calls to |compare| are
   bounded by |m|
|requiring|
   sequential time |8 * n * log(n) + 4 * n + 3|
   parallel time |6 * log(n) * log(n) + 2|
   storage space |3 * n * m + 2 * m|
```

Outline

- **Logical Foundations and Potential Use Cases**
- **TiML: A Functional Language for Practical Complexity Analysis with Invariants**
- **Complexity of Interaction**

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Logical Foundations and Potential Use Cases

TiML: A Functional Language for Practial Complexity Analysis with Invariants

- ML-like language with time-complexity annotations in types
- uses indexed types to express size and worst-case runtime complexity
- allows refinment sorts to constrain indices
- focus is on user-defined annotations, efficient type checking and usability
- allows pattern based type inference, eg. incorporating the Master Theorem

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Complexity of Interaction

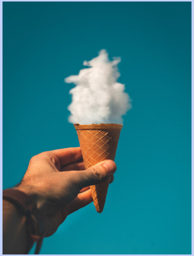
- runtime and space complexity analysis of interaction net systems
- uses sized types and scheduled types, the latter govern productivity of rules in parallel computation
- INs provide an intermediary representation of ML-like languages
- graph-based computation model generalising linear logic proof nets

Use Cases

High Performance Computing

Edge/Fog/Cloud Computing

Cloud Tenant



Cloud Provider

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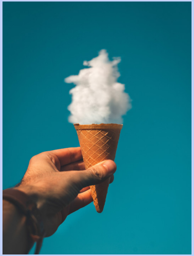

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Execution Platform

Edge/Fog/Cloud Computing

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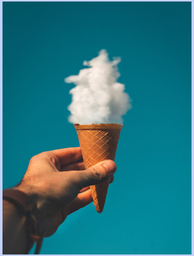
Automation aka

Type Inference



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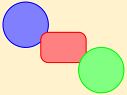

Resource-Aware

Programming

Execution Platform

Edge/Fog/Cloud Computing

Automation aka

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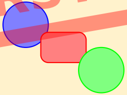
FIRST CLASS PROPERTIES



Resource-Aware Programming

Execution Platform

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TiML: A Functional Language for Practical Complexity Analysis with Invariants

A “third way” for Resource Analysis

Example

```
datatype list α : {ℕ} = Nil of list α {0}
| Cons of α * list α {n} --> list a {n+1}

fun foldl [α β] {m n : ℕ} (f : α * β -m-> β acc (l : list α {n})
    return β using (m+4) * n =
    case l of
    [] => acc
    | x :: xs => foldl f (f (x, acc)) xs
```

indexed type system induces the following constraint problem

$$\forall m, n, n' \; n' + 1 = n \Rightarrow m + 4 + (m+4)n' \leqslant (m+4)n$$

Peng Wang, Di Wang, and Adam Chlipala.
TiML: A Functional Language for Practical Complexity Analysis with Invariants.
Proc. ACM on Programming Languages, 1(OOPSLA):79:1–79:26, 2017.

Type Checking and Inference

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Usability

[...] an undergraduate student with background in SML took just one day to become fluent in writing and annotating TiML programs.

Interlude: Automated Amortised Resource Analysis

Example (TiML benchmark example)

```
empty x = (nil,nil);

checkF (f,r) = match f with
                | nil -> (rev(r),nil)
                | (x::xs) -> (f,r);

snoc (queue,x) = match queue with
                | (f,r) -> checkF(f,x::r);

enq n = match n with
                | 0 -> empty()
                | S n' -> snoc(enq(n'),n');

main = enq 3;
main = ([0],[3,2,1])
```

Definition (Annotated Type System for TRSs (selection))

$$\frac{f \text{ a function symbol} \quad [A_1 \times \cdots \times A_n] \xrightarrow{p} C \in \mathcal{F}(f)}{x_1 : A_1, \ldots, x_n : A_n \,|\!\!\frac{p}{\quad}\, f(x_1, \ldots, x_n) : C}$$

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Theorem

let TRS $\mathcal{R}$ and subsitution σ be well-typed, suppose $\Gamma \mid\!\!\frac{p}{\quad} t{:}\,A$ and $t\sigma \xrightarrow{\mathrm{i}}{}^{m}_{\mathcal{R}} v$ then

$$\Phi(\sigma{:}\,\Gamma) - \Phi(v{:}\,A) + p \geqslant m$$

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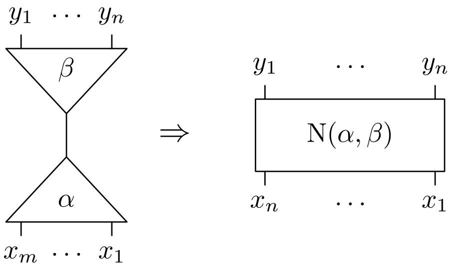
Complexity of Interaction

A Logic-Based Computation Model for Distributed Computing

Definition

- graph-based
- linear logic proof nets
- benign parallel computations
- asynchronous, local inferences



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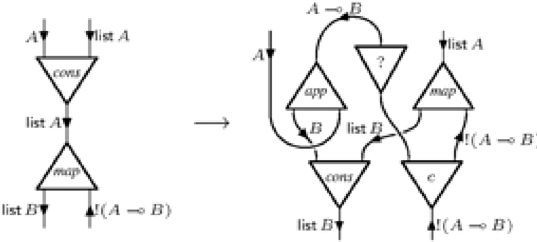

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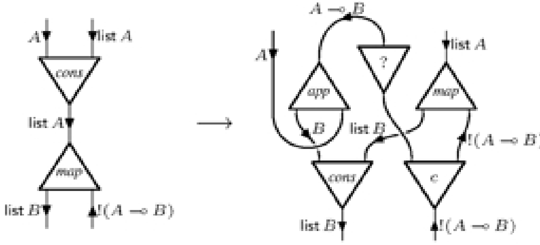

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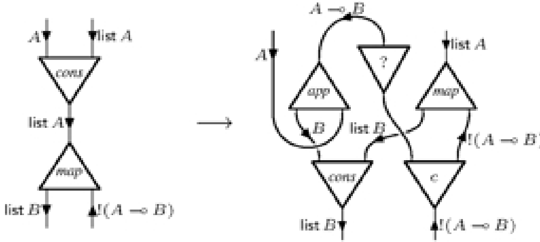

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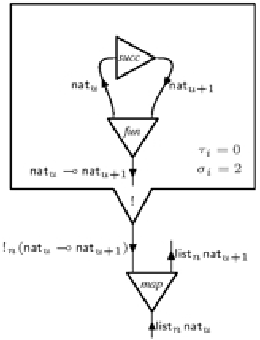
- intermediary representation language, programs need to be compiled to
- resource analysis für sequential/parallel/distributed computation, no tool support

Implementation of Interaction Nets on a Grid

computation is localised

Complexity of Interaction



Definition

- the types associated to the ports are refined by sized types and scheduled types
- runtime/space/productivity analysis
- provides a resource analysis for sequential and parallel execution
- scheduled types guarantee availability pace of data
- resource analysis works for higher-order, based on a weak sequential cost model

S. Gimenez, GM.
The Complexity of Interaction.
In *Proc. 43th POPL*, pages 243-255, 2016

Thank You for Your Attention