Bismuth: A Programming Language for Distributed, Concurrent & Mobile Systems

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Research Problem

From cloud computing to machine learning and the rise of IoT devices, it is apparent that the future of computing will occur in a more distributed and concurrent manner than ever before [1, 2]. However, such programs are challenging to write as few languages are designed for these tasks. As such, **this project developed Bismuth: an expressive new language designed to enable to the communication of distributed, concurrent, and mobile tasks while retaining correctness guarantees and being accessible to a general audience of programmers**. To accomplish this, I developed and used a new framework for the rapid audience-centered prototyping of programming languages.

Design Framework

1. Initial Design: Establish Audience & Purpose
- Statement of Motivations
- Case Study of Languages
- Create Initial Theory

2. Revise Design: Evaluate Expressiveness & Design Impact
- Corpus Study
  - Can express audience needs?
  - Language impact on tasks?

3. Assess Design: Analysis of Results & Conclusion
- Either: reject, revise, or deem ready for intensive methods

Bismuth

Sample Program

```
Database :: c : Channel<!ExtChoice<get: +Key;-Option<Value>,
                                    set: +Key;+Value,
                                    lock:+Key;IntChoice<
                                                -Value;+Value,
                                                +Value>>> {

  Map<Key, Value> data;
  accept(c) {
    offer c
      | get => c.send(data[c.recv()])
      | set => data[c.recv()] = c.recv()
      | lock => {
          Key k = c.recv();
          Option<Value> opt = data[k];
          match opt
            | Empty => { c[+Value]; }
            | Value v => { c[-Value;+Value];
                            c.send(data[k]); }
          data[k] = c.recv();
        }
  }
}
...
var db = exec Database;
Channel<!(get : +Key;-Option<Value>, ...)> rqs = ...
Channel<!(+Key;+Value)> setRq = ...

accept(rqs) {
  acceptWhile(setRq, true) {more(db); link(setRq, db)}
  more(db)
  link(rqs, db)
}
accept(writes) { more(db); link(setRq, db) }
weaken(db)
```

Syntax

τ ::=	*Types*	P, Q ::=	*Program*
Channel<ρ>	Channel Type	s_b	Base Statement
Program<ρ>	Program Type	$P; Q$	Sequence
τ_b	Base Type	c.send(e)	Send
ρ ::=	*Protocols*	while(e){P}	While Loop
$+\tau$	Receive	c.case(P, Q)	External Choice
$-\tau$	Send	$c[i]$	Internal Choice
$?\rho$	Why Not	more(c)	Unfold
$!\rho$	Of Course	weaken(c)	Weaken
$\rho; \rho$	Sequence	accept(c){P}	Accept Loop
ExternalChoice<ρ, ρ>	External Choice	acceptWhile(c, e){P}	Accept While Loop
InternalChoice<ρ, ρ>	Internal Choice	exit	Exit Program
		e ::=	*Expressions*
		x	Variable
		c.recv()	Receive
		exec P	Execute Program
		e_b	Base Expression

Contributions & Features

- By using Classical Linear Logic, there is **no need to distinguish between parent/child channel** & Both **linear and non-linear resources** are supported
- **Asynchronous** (Write operations are non-blocking)
- **Intermixed used of multiple channels** within each process
- Linear **resources are** easily **accessible within loops** while maintaining correctness guarantees
- Through **Accept While Loops**, protocols of duration controlled by a remote process do not have to be recognized all at once
- **Multiple processes** can **communicate over the same channel** via protocol manipulations
- **Acyclic** graph **distribution structure** allows for **flexibility and deadlock freedom**

Conclusions & Future Work

- **Bismuth has the potential to be expressive for a wide variety of distributed tasks**—representing 5/7 audience tasks with at most minor simplifications; the remaining require modifications that could be reasonably addressed by future work (parallel and closeable channels).
- Bismuth's consistent approach to distribution made programs that would otherwise require libraries easy to write.
- **Bismuth's correctness properties make some tasks (such as shared state)** as they require additional code for the language to verify them as correct. **This could be addressed through expanding what the language can understand as correct.**
- Bismuth's syntax conceals pragmatic information about what processes do due to the complexity of protocols. **Future work could explore ways of making the syntax more communicative.**

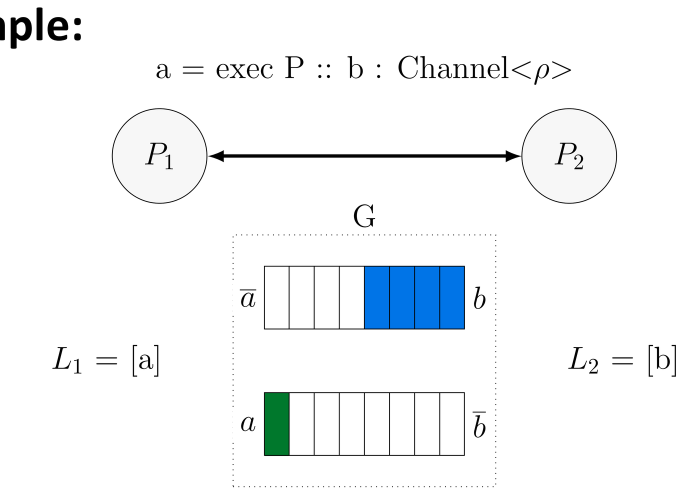
Proof Overview

Progress: If $(G; \vec{L}; \vec{P})$ ok then either $(G; \vec{L}; \vec{P})$ $done$ or there exists $(G'; \overrightarrow{L'}; \overrightarrow{P'})$ such that $(G; \vec{L}; \vec{P}) \mapsto (G'; \vec{L}'; \vec{P}')$.

Preservation: If $(G; \vec{L}; \vec{P})$ ok and $(G; \vec{L}; \vec{P}) \mapsto (G'; \vec{L}'; \vec{P}')$, then $(G'; \vec{L}'; \vec{P}')$ ok.

Type Safety, Deadlock Freedom: Inherent given above proofs.

Configuration Example:



References

[1] Lindley, S., Morris, J.G. (2015). A Semantics for Propositions as Sessions. In: Vitek, J. (eds) Programming Languages and Systems. ESOP 2015. Lecture Notes in Computer Science, vol 9032. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-46669-8_23

[2] Akshitha Sriraman. "Enabling Hyperscale Web Services". PhD thesis. University of Michigan, 2021. doi: https://dx.doi.org/10.7302/2847.

MQP Paper

PW Poster

Web Compiler

Website