Bachelor Proposals

Programming Languages, Logic, and Software Security

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November, 2025

AARHUS UNIVERSITY

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The Overarching Question

How do we make computer systems provably safe, reliable, secure and performant?

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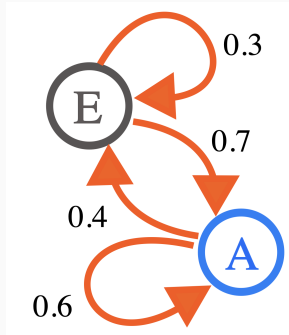
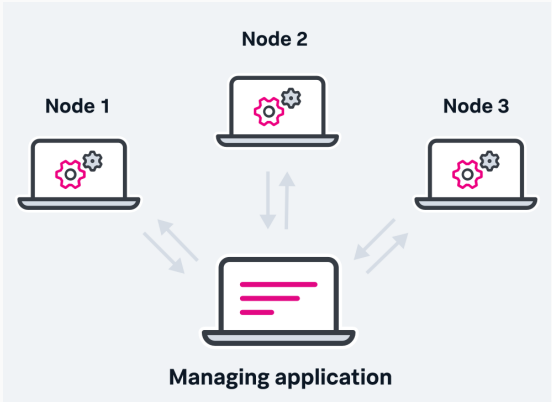
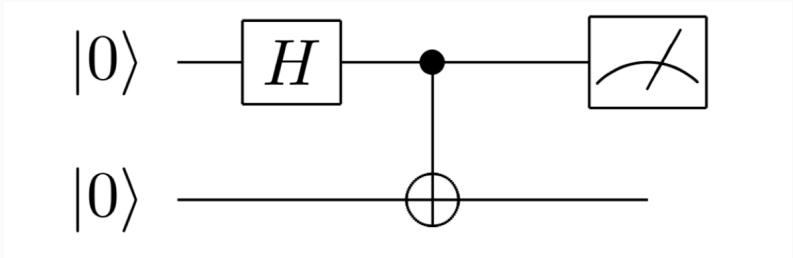
Programming language design



Probabilistic systems



Concurrency



Quantum circuits & programs

Research Areas

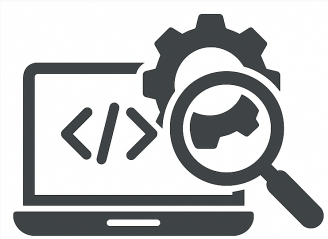
$\Gamma \vdash e : \tau$

Type systems

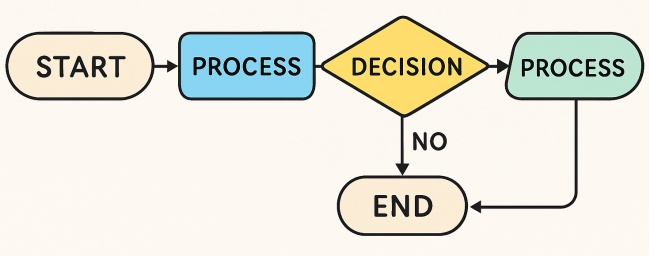
Iris

Logics

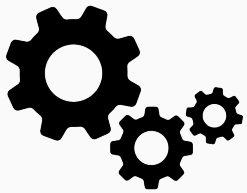
Proof assistants



Static program analysis



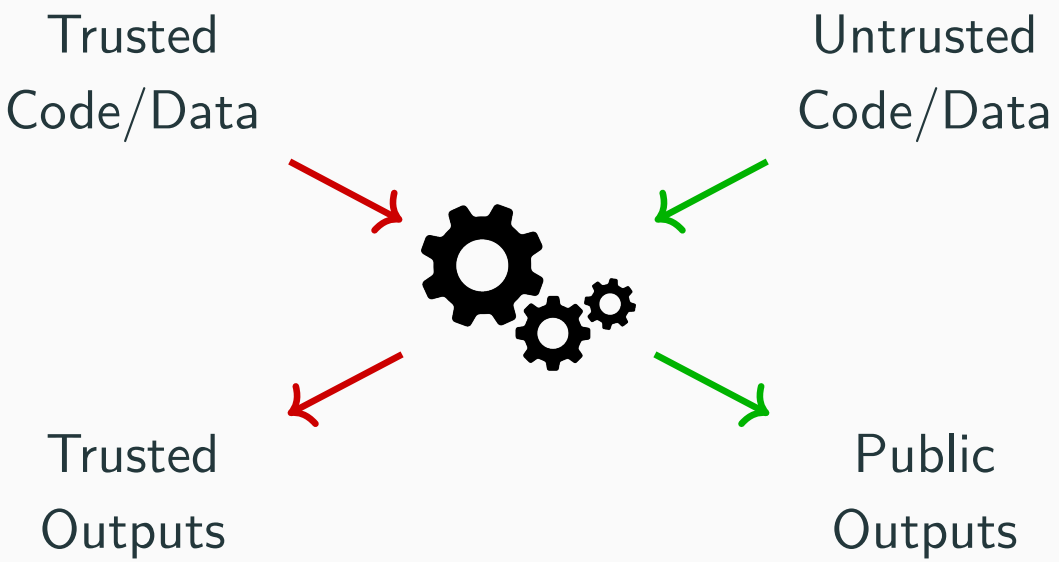
Algorithms & complexity



Automated reasoning (SAT/SMT)

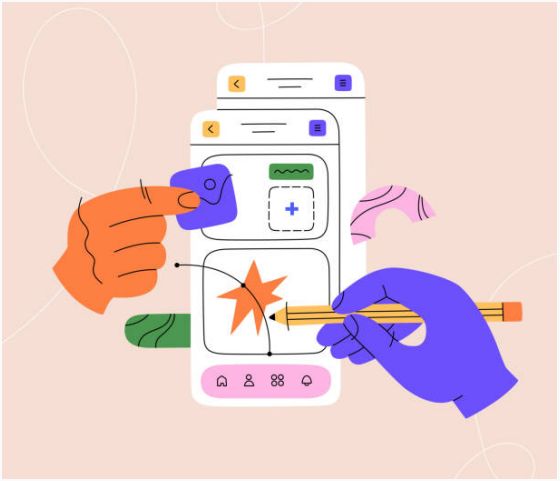
Troupe: A Privacy-Aware Programming Language

A language with runtime security monitoring



Example Projects in Troupe

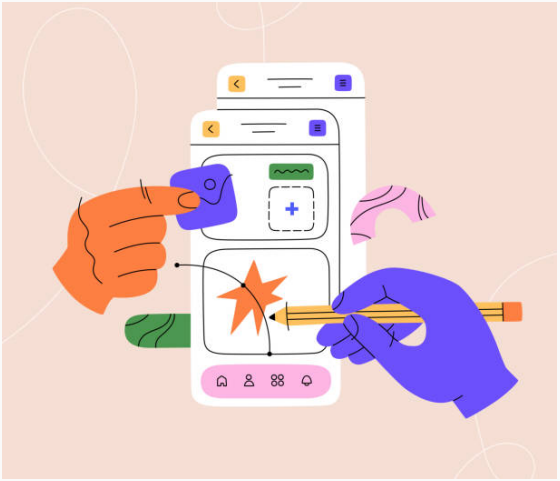
Privacy Aware User Interface



How do we make UIs
adaptive to privacy environments?

Example Projects in Troupe

Privacy Aware User Interface



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- Develop a UI library in Troupe
- Context-aware privacy
- Showcase on a messaging app

Example Projects in Troupe

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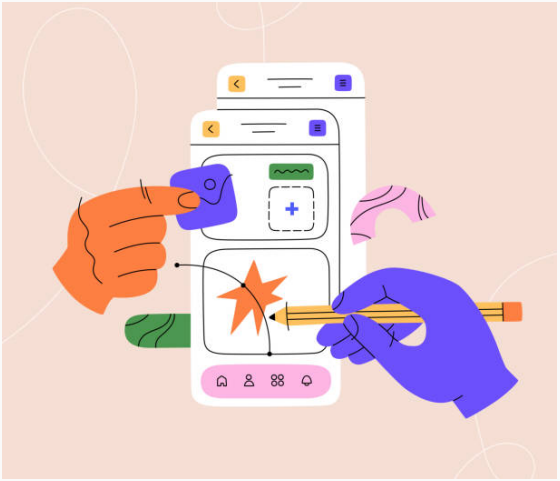

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Secure Agentic Coding

Can AI generate code preserving
security/privacy constraints?

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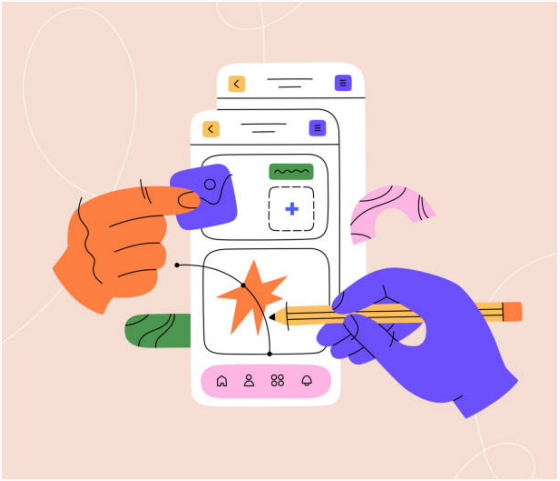
Example Projects in Troupe

Privacy Aware User Interface



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Secure Agentic Coding

Can AI generate code preserving
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- LLM code generation for Troupe
- Incorporate security concepts lacking in training

Termination Analysis

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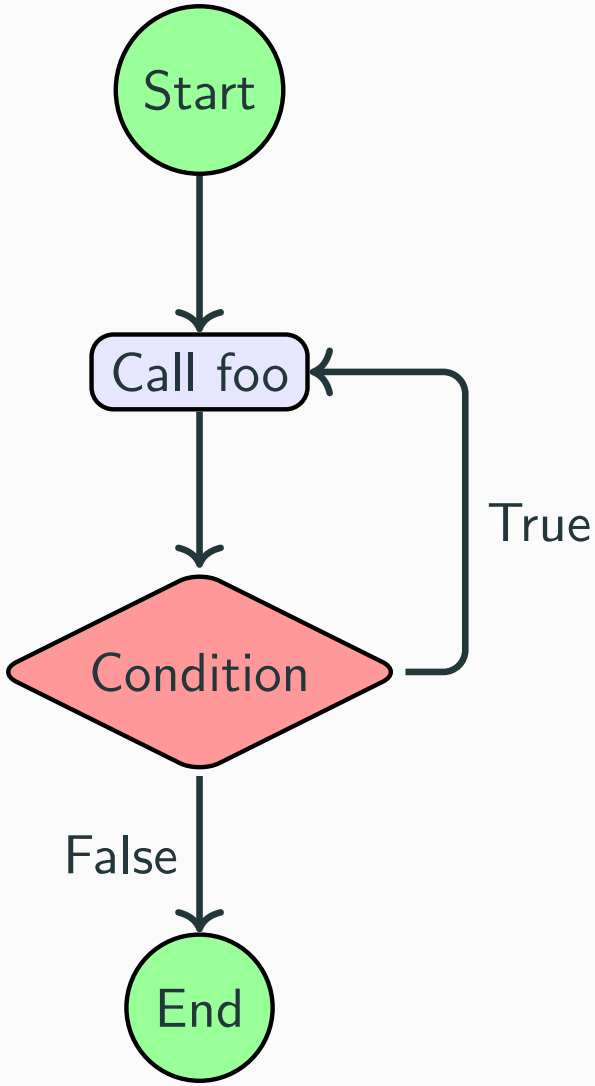


Termination Analysis in Flix

- Algebraic data types
- Type inference
- Polymorphic effects
- First-class Datalog constraints

```
// Termination via recursion on structurally smaller data
def map(f: a->b, l: List[a]): List[b] =
    match l {
        case Nil     => Nil
        case x :: xs => f(x) :: map(f,xs)
    }
```

- What methods exist for termination checking?
- How to implement in the Flix compiler?

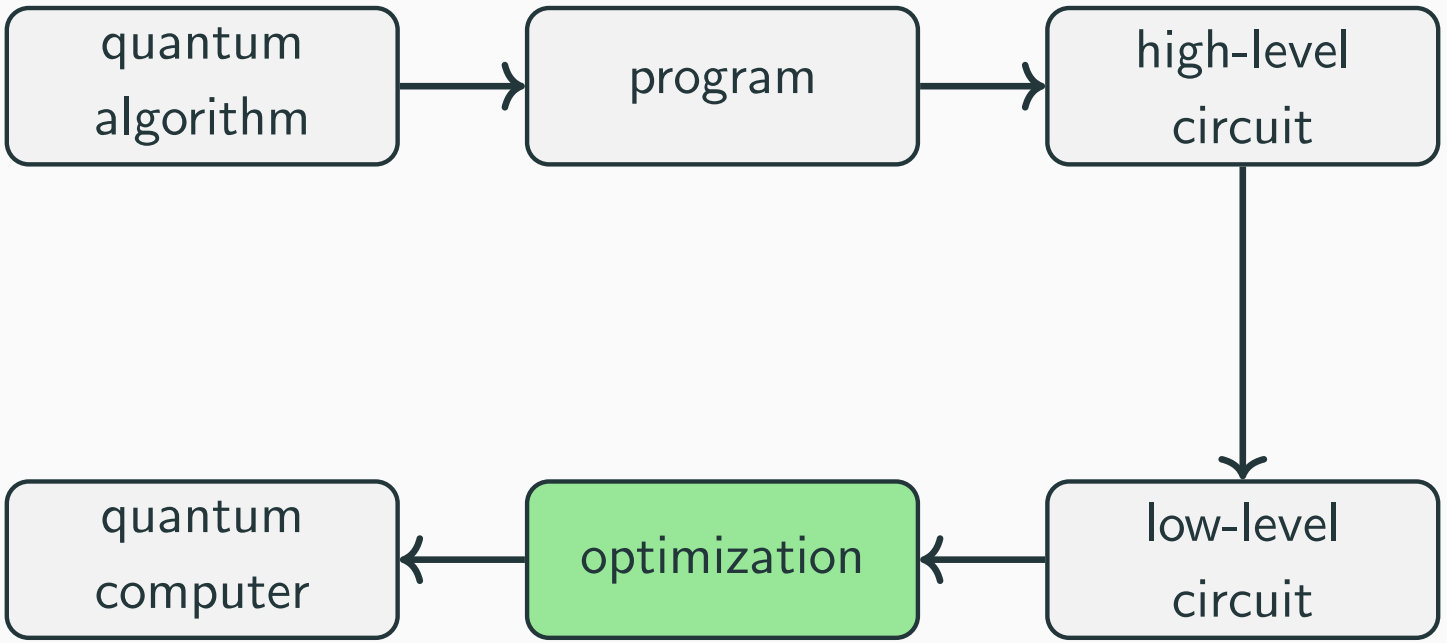
Other Projects in Flix

- Algebraic data types
- Type inference
- Polymorphic effects
- First-class Datalog constraints

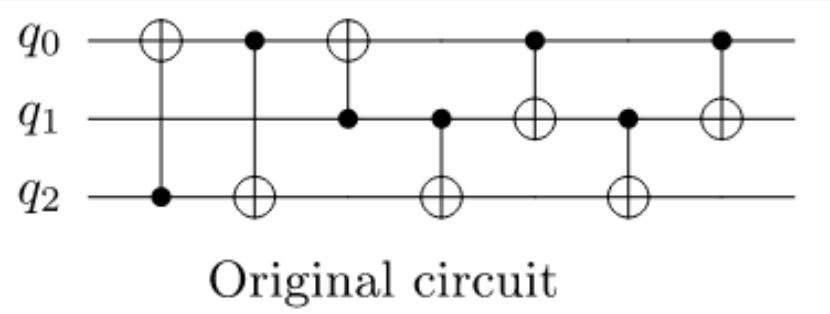
Contribute to the growth of Flix:

- Code formatter
- Program optimizations
- Faster type inference
- Extend the standard library
- ...

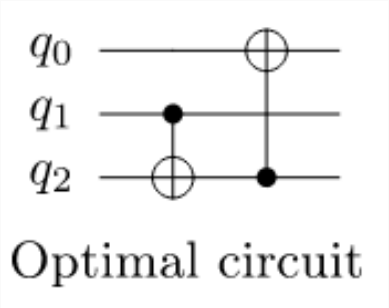
Quantum Circuit Synthesis



Quantum Circuit Optimization

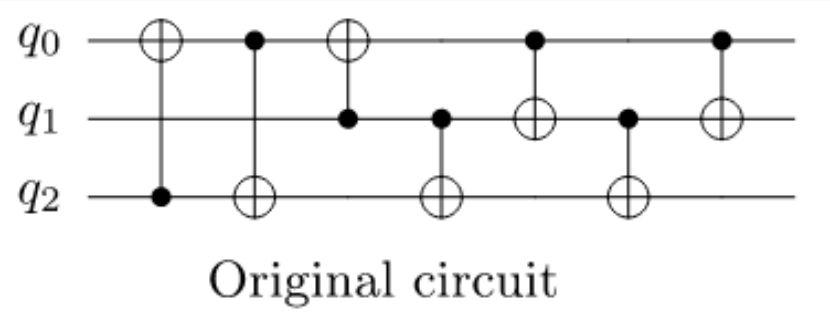


Original circuit



Optimal circuit

Quantum Circuit Optimization



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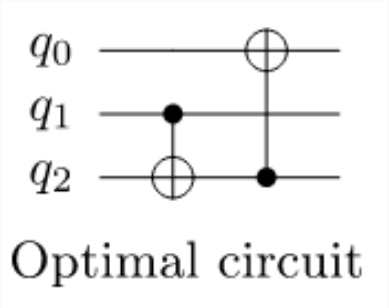
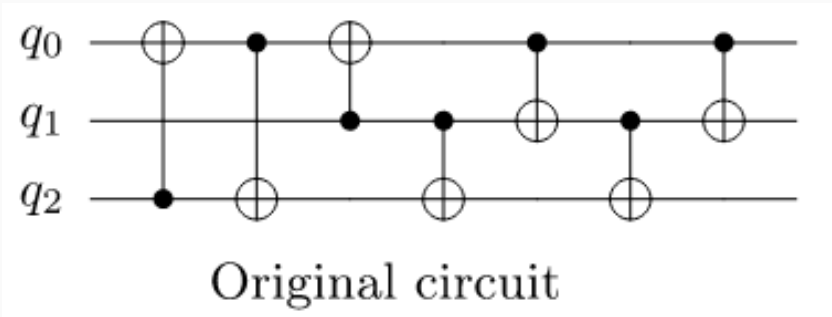


Optimal circuit

- How can we optimize circuits efficiently?
- What quantum gate sets can we target?
- What metrics can we optimize for? E.g.
  - Circuit Size
  - Circuit Depth
  - Gate count
  - Noise

Quantum Circuit Optimization



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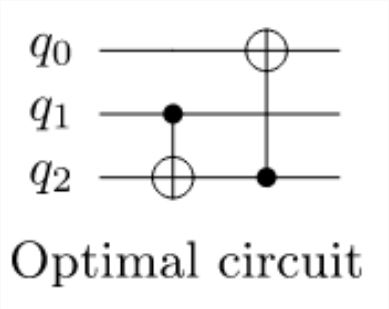

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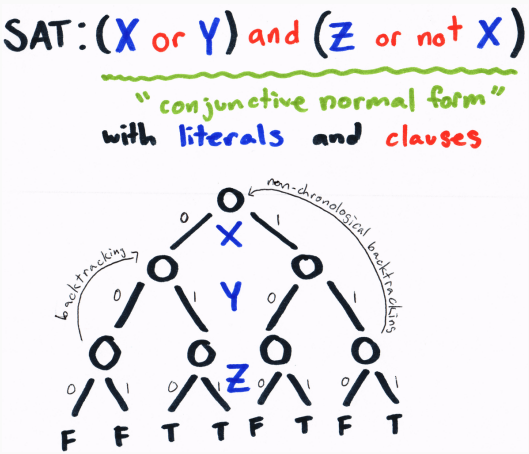

QSynth!

Safe Compilation to WebAssembly and LLVM

Safe Compilation to WebAssembly and LLVM


Safe Compilation to WebAssembly and LLVM


- How do I compile between mainstream languages?
- How do I prove that my compilation is correct?
  - Property based testing
  - Mechanization
  - ...

Dependently Typed Programming

"Well-typed programs cannot go wrong." – Robin Milner

Well...

```
var x:Int;
...
//what if x is 0?
println(42/x);
```

```
def get(a:Array[Int], i:Int):Int={
   //What if i>=a.len?
 return a(i);
}
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```

Q: How can we prevent such errors at compile time?

Dependently Typed Programming

A: Dependent Types!

```
var x:Int[v|v!=0];
...
//x != 0
println(42/x);
```

```
def get(a:Array[Int], i:Int[v|v<a.len]):Int={
    // i<a.len
 return a(i);
}
```

Verified Functional Programming in Agda

- A dependently-typed programming language
- A proof assistant

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Curry–Howard correspondence!

Propositions $\iff$ Types

Proofs $\iff$ Programs

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Propositions $\iff$ Types

Proofs $\iff$ Programs

- What are the foundations of dependently-typed programming?
- How do we express program correctness as dependent types?
- How can we verify simple algorithms using Agda?

What next?

- Meet us after this lecture
- Check our project descriptions on brightspace
- Email us, drop by our offices

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Also reach out if

- You like a project but are in doubt
- You are passionate about an idea/project not listed