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Romeo & Juliet:
Next-gen Robot Programming

Jesper Öqvist

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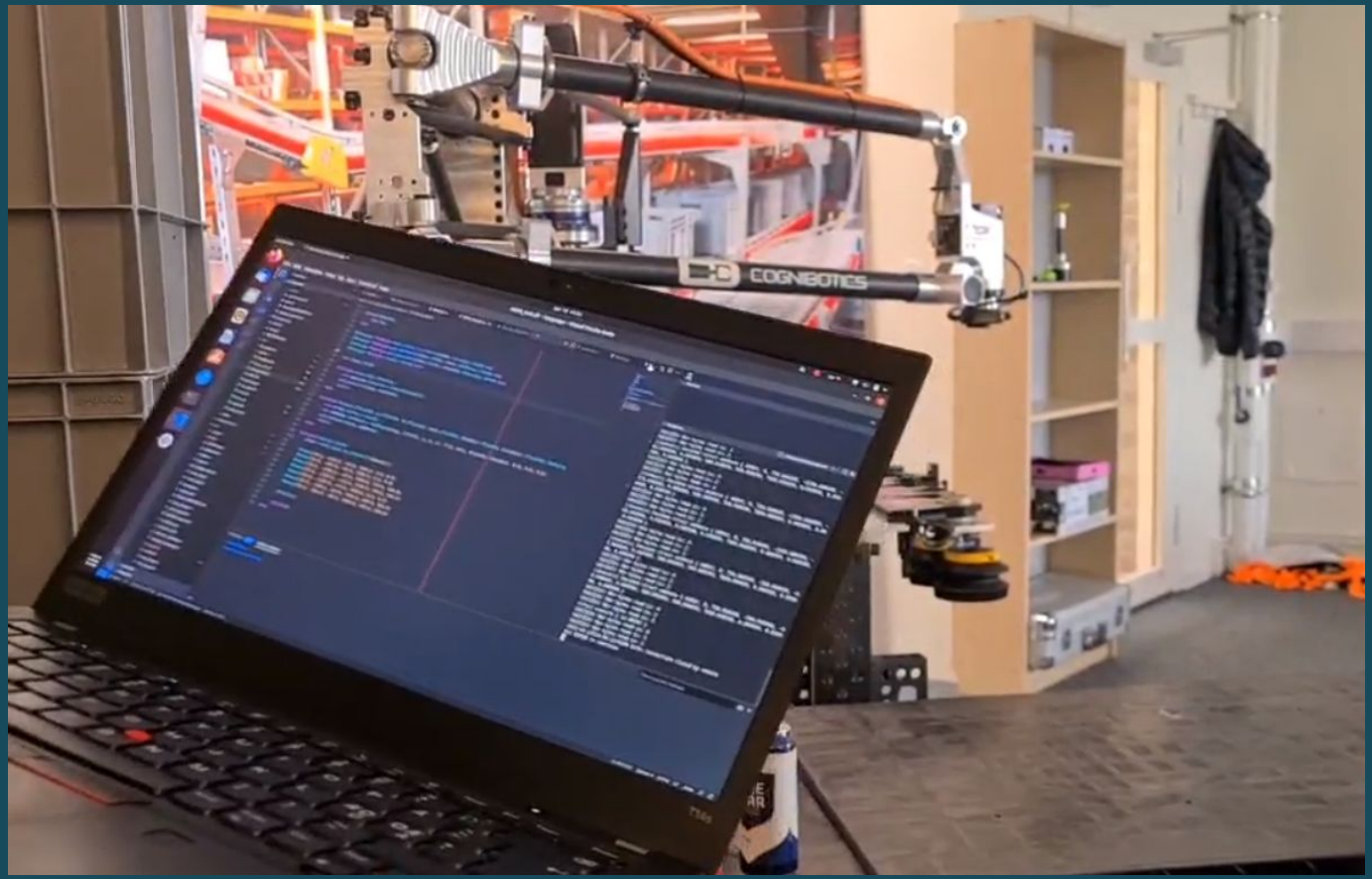

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Julia

Dynamic language for scientific computing:

- ★ Managed memory (GC)
- ★ Minimal syntax
- ★ Powerful libraries
- ★ JIT-compiled (LLVM)
- ★ Optional type declarations
- ★ First-class functions
- ★ Multimethods

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Julia Syntax

```
f(x) = 2x
```

```
function mul2(x::Int)::Int
  x + x
end
```

```
for i in [1,2,3]
  println(mul2(i))
end
```

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Data Types

```
struct Foo{T}
  x::T
  y::String
  z::Vector{T}
end
```

No member functions - instead polymorphic multimethods

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Multimethods

```
struct Bird end
struct Fly end


can(::Fly,  ::Bird) = "fly cannot bird"
can(::Bird, ::Fly ) = "bird can fly"
can(::Any,  ::Any ) = "unknown"


can(Fly(), Bird())
can(Bird(), Fly())
```

Multimethods / Multiple Dispatch - runtime selection of most specific method (on all aruments).

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Polymorphism

```
struct Foo{T}
  x::T
end


unwrap(foo::Foo{T}) where T = foo.x



setindex!(arr::Array{T,D}, x::T, i::Int) where {T, D} = ...
```

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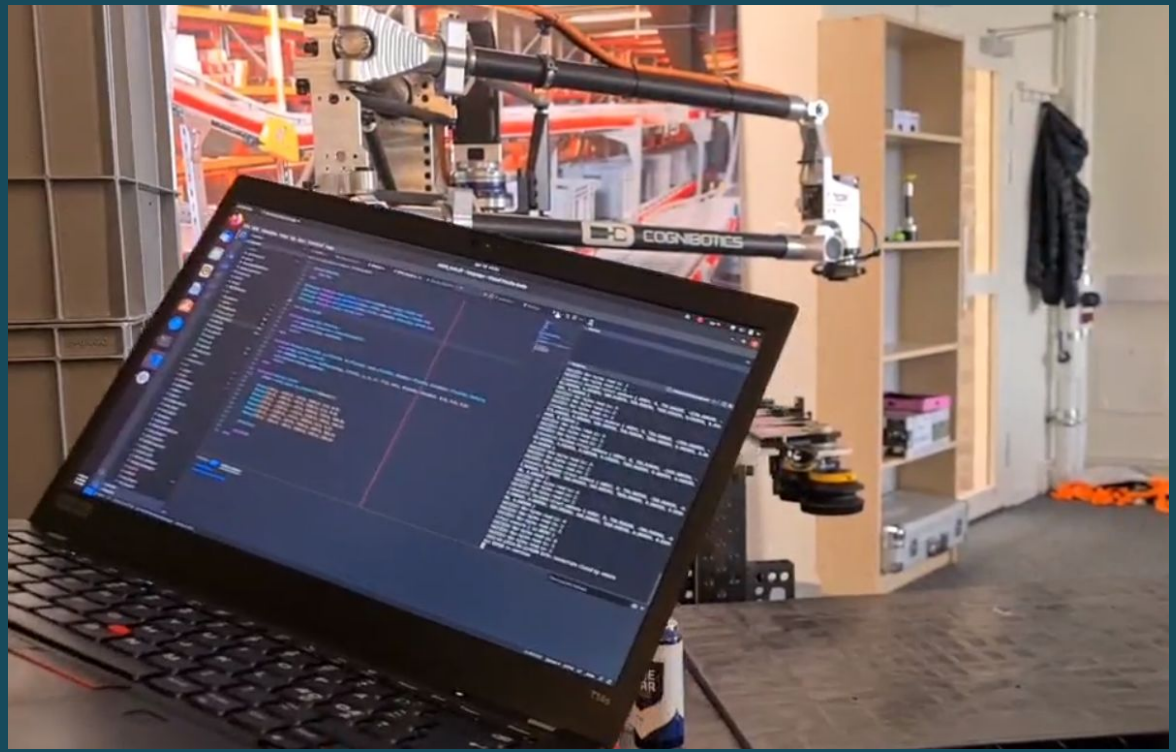
Juliet = Julia for Robots

- Statically typed Julia
- Compiled to bytecode
- Custom GC
- Robot VM (Romeo/RVM)
- IDE for robot programming



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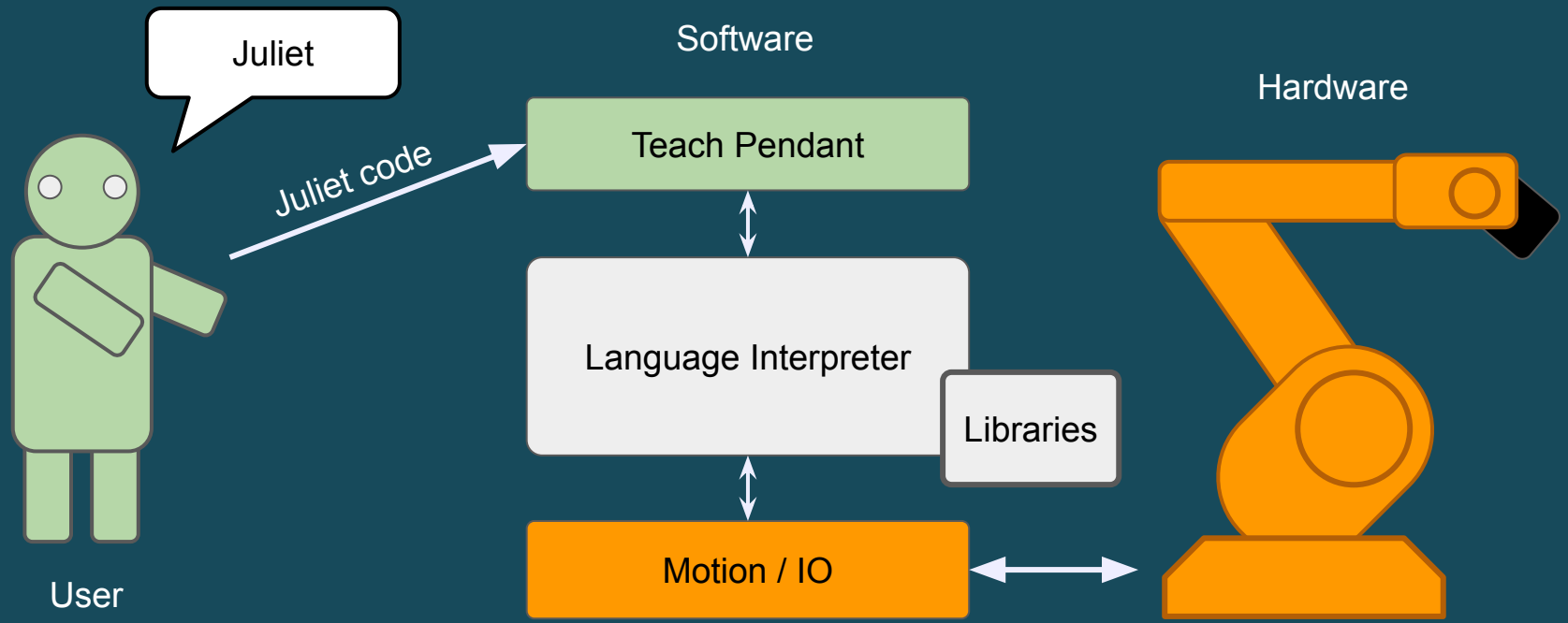
Highlevel System View



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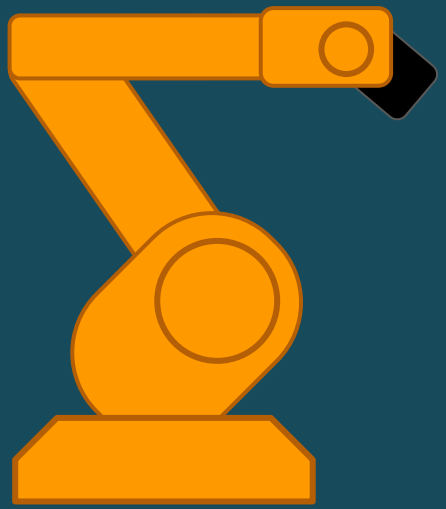
Robot Considerations

Slow predictable execution > fast unpredictable JIT

Static typing > runtime errors

Static allocations > dynamic arrays/lists

Robot tasks:
Welding
Painting
Machining
Pick/place



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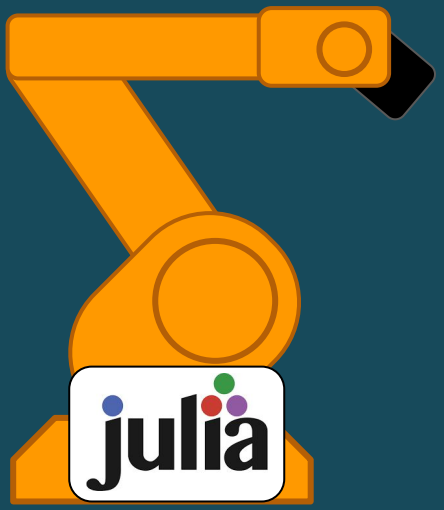
Why Juliet for Robots?

- **intuitive / minimal syntax**
- **powerful type system**
- **robot motions as library code**
- functional programming
- formalize backwards-stepping behavior
- access to high-quality libraries (Julia packages)



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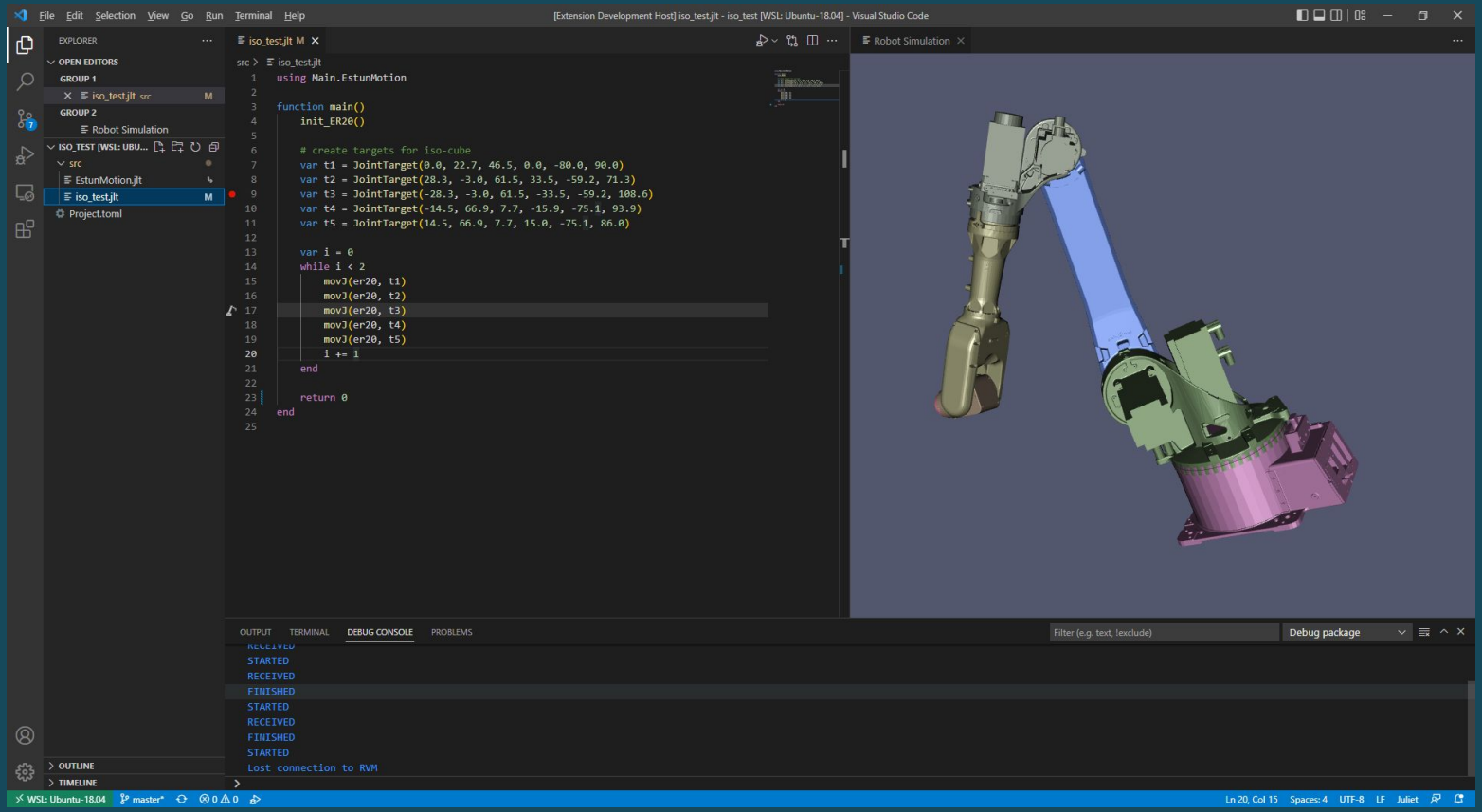

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The Juliet Team

About 15 people contributing to Juliet runtime, compiler, GC, libraries, etc.

2 people working on the compiler:
Jesper Öqvist
Erik Jansson

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Development Process

Incremental development
Divide and conquer, don't worry about making it perfect from the start.

Regression test!
Each new feature should be tested.

CI/CD
Run tests on a server for each commit (GitLab)

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Juliet Compiler

- Written in C
- Scanner: Flex-generated
- Parser: Bison-generated (GLR)
- Semantic analysis: visitor-based
- Code generation: bytecode

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Juliet Parsing

Julia is not context-free LR(1) because it allows almost any kind of whitespace anywhere

```
if x println(x) end

if x
  println(x)
end
```

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Juliet Parsing

Julia is not context-free LR(1) because it allows almost any kind of whitespace anywhere

```
if x(y, z)
end


if x
  (y, z)
end

function f(x)
  return x
  + 3
end
```

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Julia Parsing

Julia is not context-free LR(1) because it allows almost any kind of whitespace anywhere

```
function f(x)
  return x
  + 3
end
```

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Julia is not LR(1)

```
program = es

// Expression list:
es = e | es w e

// Expression:
e  = n | n w EQ e

// Name:
n = ID

// Whitespace:
w = WHITESPACE
```

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Juliet Modules

```
module Foo
  function foo() end
end

Main.Foo.foo()
```

Name analysis passes:

1. Find all modules and structs. Map structs to respective modules.
2. Declare all function names (in modules), lookup parameter types.
3. Do local name lookup and call resolution.
4. Do a type check pass.

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Juliet Type Analysis

The subtype algorithm is described in Jeff Bezanson's Thesis.

Just implement that ->

$$\frac{{}^{B}_{A}X^{L}, \Gamma \vdash T \le S}{\Gamma \vdash \exists\, {}^{B}_{A}X\ T \le S} \qquad \frac{{}^{B}_{A}X^{R}, \Gamma \vdash T \le S}{\Gamma \vdash T \le \exists\, {}^{B}_{A}X\ S} \qquad \frac{}{\Gamma \vdash X \le X}$$

$$\frac{{}^{B}X^{L}, {}_{A}Y^{L}, \Gamma \vdash B \le Y \ \vee\ X \le A}{{}^{B}X^{L}, {}_{A}Y^{L}, \Gamma \vdash X \le Y} \qquad \frac{{}^{B}_{A}X^{R}, Y^{R}, \Gamma \vdash B \le A}{{}^{B}_{A}X^{R}, Y^{R}, \Gamma \vdash X \le Y}$$

$$\frac{{}^{B}_{A}X^{R}, \Gamma \vdash T \le B}{{}^{B}_{A\cup T}X^{R}, \Gamma \vdash T \le X} \qquad \frac{{}^{B}_{A}X^{R}, \Gamma \vdash A \le T}{{}^{T}_{A}X^{R}, \Gamma \vdash X \le T}$$

$$\frac{{}_{A}X^{L}, \Gamma \vdash T \le A}{{}_{A}X^{L}, \Gamma \vdash T \le X} \qquad \frac{{}^{B}X^{L}, \Gamma \vdash B \le T}{{}^{B}X^{L}, \Gamma \vdash X \le T}$$

Bezanson, J. W. *Abstraction in Technical Computing*. PhD thesis, Department of Electrical Engineering and Computer
Science, Massachusetts Institute of Technology. June, 2015.

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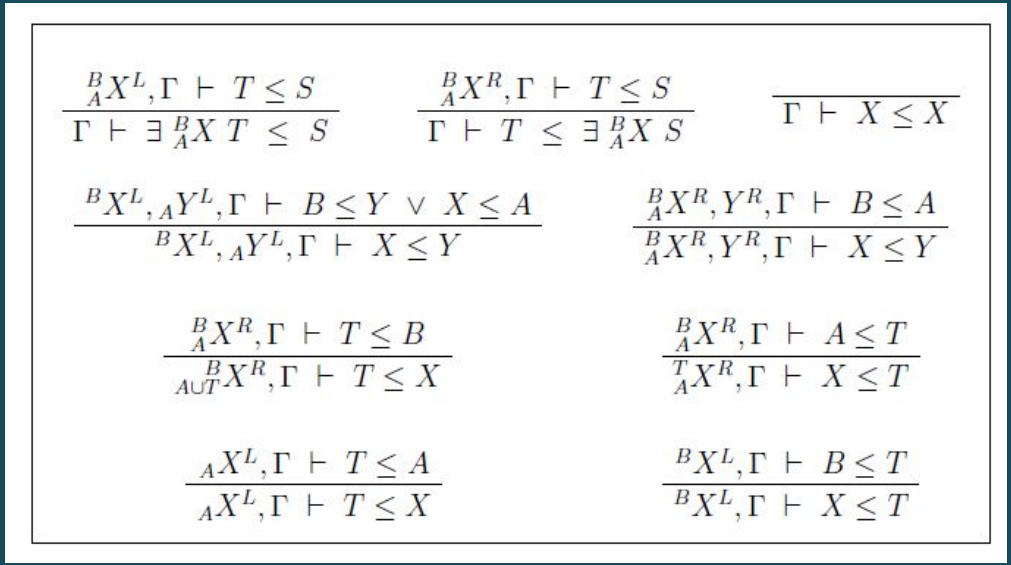
Juliet Type Analysis

The subtype algorithm is described in Jeff Bezanson's Thesis.

Just implement that ->

Actually it's not that simple. Must avoid infinite expanding types. Must be precise with keeping track of separate instances of typenames.

```
struct Onion{A, B}
  onion::Onion{B, A}
end
```



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Arrays

Array indexing is translated to function calls:

```
var a = zeros(Int8, 10)
a[4] = 10                   # setindex!(a, 10, 4)
println(a[4])               # getindex(a, 4)
```

Multimethods make it possible to overload the indexing operator for custom types!l

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Exceptions

```
try
  error("oopsie")
catch e
  println("failed")
finally
  return 0
end
```

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Union Dispatch

Formal parameters can have union type:

```
function foo(x :: Union{Bool, String}) end
foo(true)
foo("x")
```

Conversely, multiple functions can be dispatched with a union typed argument.

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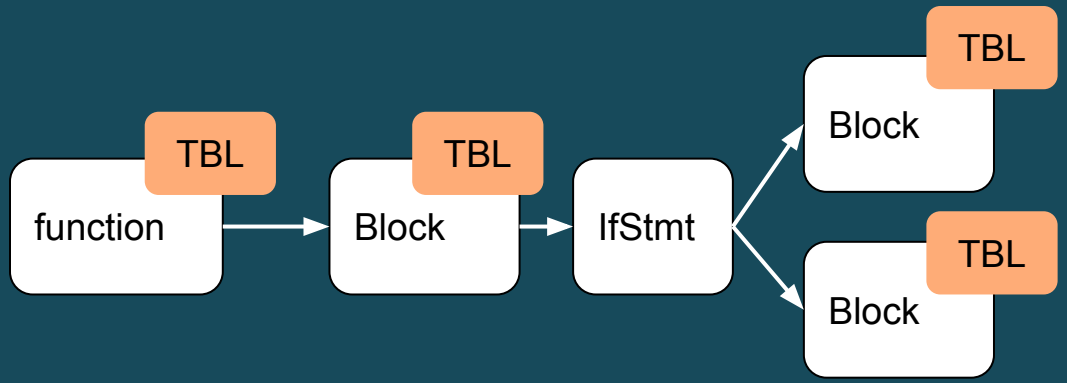
Declaration Chains

The typical design for name analysis with visitors uses name tables at each scope (function, block, etc).



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Declaration Chains

Idea: instead store chain of previous declarations from each name use, mapping out the reverse pre-order of matching name declarations.