Designing a New Language for Safety: Fuzion

A minimal language for safety-critical systems

TOKIWA
software

Who is this guy?

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‘90-‘94	AmigaOberon, AMOK PD
‘97	FEC Eiffel Compiler Sparc / Solaris
‘98-‘99	OSF: TurboJ Java Compiler
‘00-‘01	PhD on real-time GC
‘02-‘19	JamaicaVM real-time JVM based on CLASSSPATH / OpenJDK, VeriFlux static analysis tool
‘20-…	Fuzion
‘21-…	Tokiwa Software

Motivation

Many languages overloaded with concepts like classes, methods, interfaces, constructors, traits, records, structs, packages, values, …

➡ Fuzion has one concept: a feature

Today's compilers and tools are more powerful

➡ Tools make better decisions

Systems are safety-critical

➡ we need to ensure correctness

Fuzion Summary

Fuzion

- ➡ uses the **feature** as its main concept
- ➡ is **statically typed**
- ➡ has **inheritance** and **redefinition**
- ➡ uses **value types** and **dynamic (ref) types**
- ➡ encourages **immutability**
- ➡ offloads tasks and decisions from developers to **tools**

Backing Company

- supports development of Fuzion
- currently three employees
- hiring
- searching for funding

Safety-Critical Systems

Definition (Wikipedia)

- ➡ a system whose failure or malfunction may result in []:
  - death or serious injury to people
  - loss or severe damage to equipment/property
  - environmental harm
- ➡ often require certification (IEC61508, DO178C, etc.)

Safety-Critical Systems

Certification typically requires

- ➡ defined SW development process
- ➡ traceability
  - requirements ↔ code ↔ validation ↔ results
- ➡ rigorous verification and validation
  - static analysis can help

Fuzion Language Tutorial

Not part of this talk

➡ online at **flang.dev**

This talk will show how

➡ Java maps to Fuzion

Feature Examples

Features used as routines with code

Feature Examples

Features used as routines with code

```
HelloWorld is
  say "Hello World!"
```

Feature Examples

Nesting of Features

```
HelloWorld is
  hw is
    say "Hello World!"

  hw
```

Feature Examples

Features with arguments

```
HelloWorld is
  hw(name string) is
    say "Hello $name!"

  hw "World"
```

Feature Examples

Features with inner features

```
HelloWorld is
  hw(name string) is
    run is
      say "Hello $name!"

  x := hw "World"
  x.run
```

Feature Examples

Features with inner features

```
HelloWorld is
  hw(name string) is
    run is
      say "Hello $name!"

  x := hw "World"
  x.run
```

Fuzion code consists of feature declarations and feature calls.

Design by Contract

Design by Contract

Features define their behavior

- ➡ pre-condition: what has to hold before a call?
- ➡ post-condition: what guarantee is given after the call?
- ➡ concept presented by Betrand Meyer back in 1986

Design by Contract: Example

```
sqrt(a i32) i32
  pre
    a >= 0
  post
    result * result <= a,
    (result + 1) * (result + 1) > a
is
  ...
```

Controlling Contract Checks

Checking contracts dynamically

- ➡ will introduce run-time overhead
- ➡ may be prohibitively expensive
- ➡ may be required for safety

Solution

- ➡ qualified contracts

Qualified Contracts

```
sqrt(a i32) i32
  pre
    debug: a >= 0
  post
    debug 5 : result * result <= a,
    debug 5 : (result + 1) * (result + 1) > a
is
  ...
```

Contract Qualifiers

Fuzion contract qualifiers

- ➡ `safety`
- ➡ `debug`
- ➡ `debug n`
- ➡ `pedantic`
- ➡ `analysis`

Contracts for Static Analysis

```
max(a Sequence<i32>) i32
  pre
    debug: !a.isEmpty
  post
    debug: a ∀ x -> x <= result
    debug: a ∃ x -> x = result
    analysis : ∀<i32> x -> x ∈ a : x <= result
    analysis : ∃<i32> x -> x ∈ a && x = result
is
```

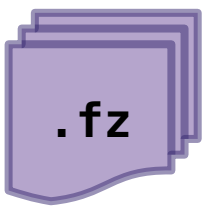
Design-by-Contract & Certification

Contracts provide

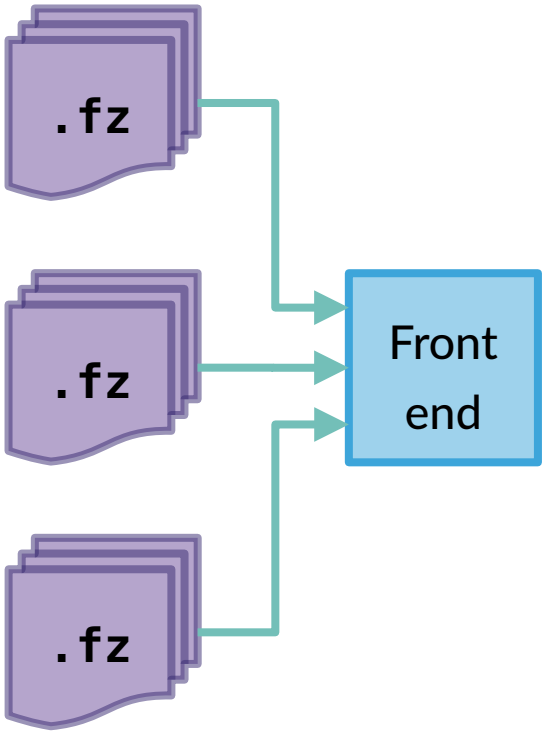
- ➡ direct way to add formal requirements to code
- ➡ means to verify these requirements at runtime
- ➡ means to define (or generate) tests
- ➡ formal analysis tools the required input

Fuzion Toolchain Design

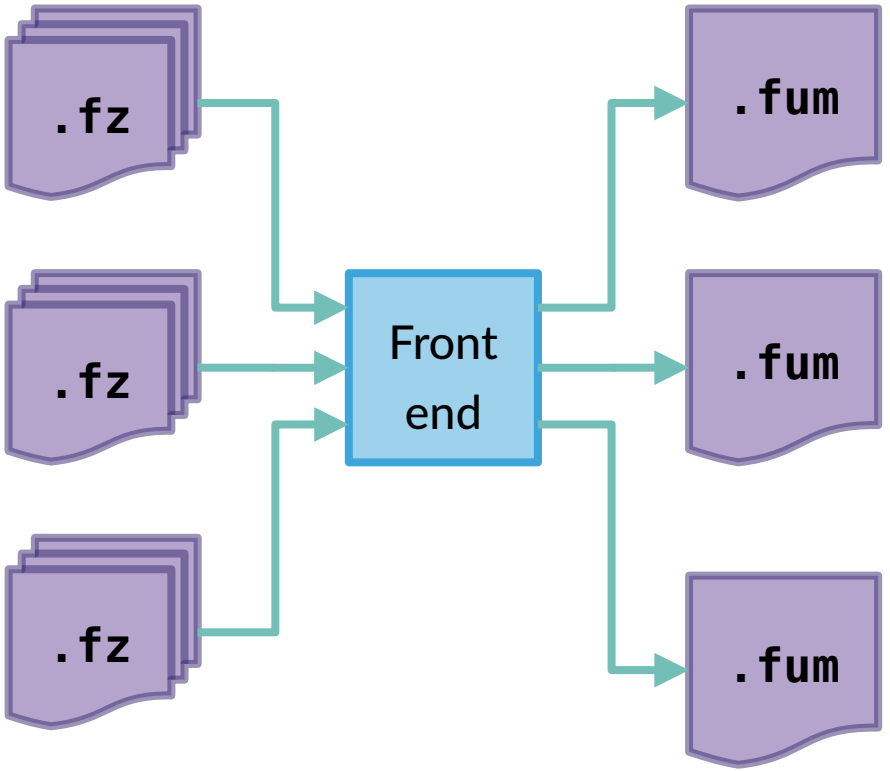
Fuzion Toolchain Design



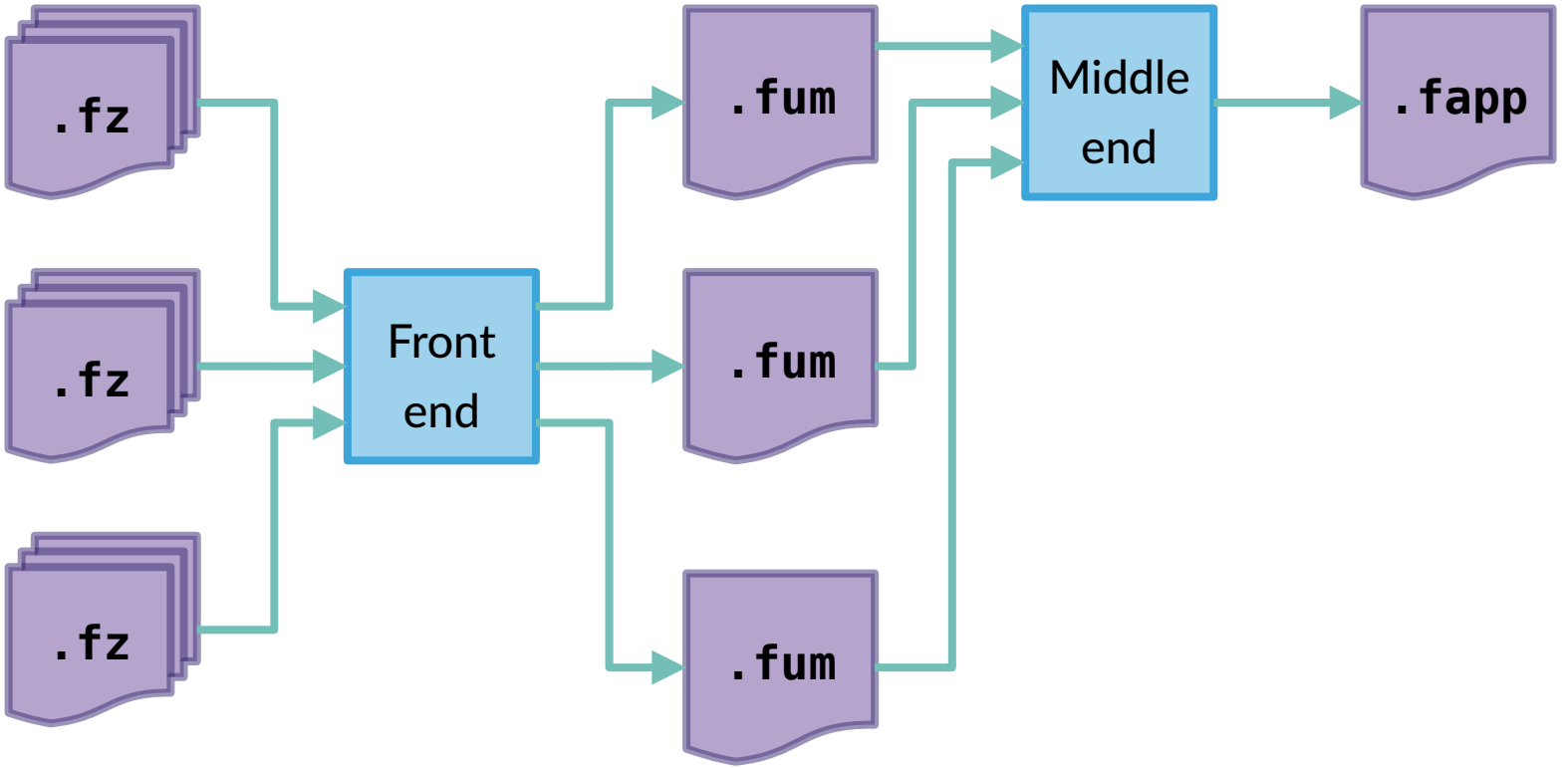
Fuzion Toolchain Design



Fuzion Toolchain Design



Fuzion Toolchain Design



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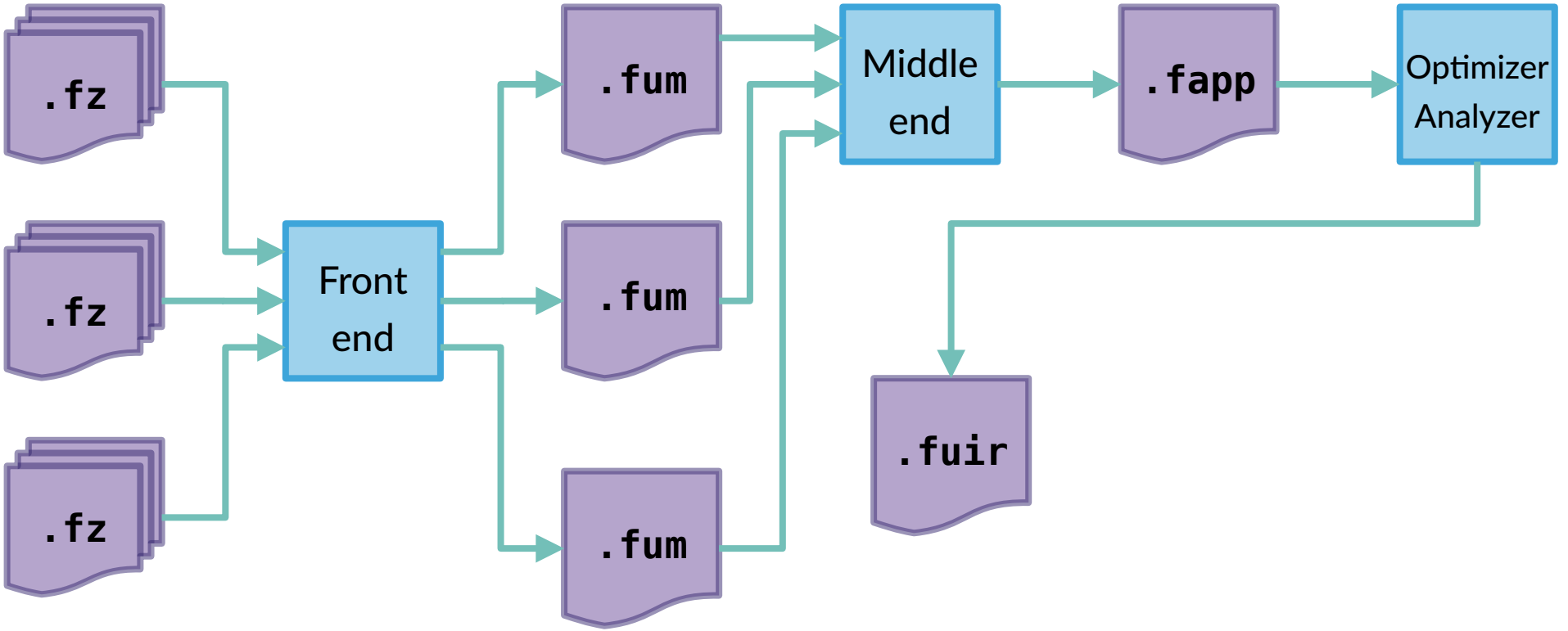
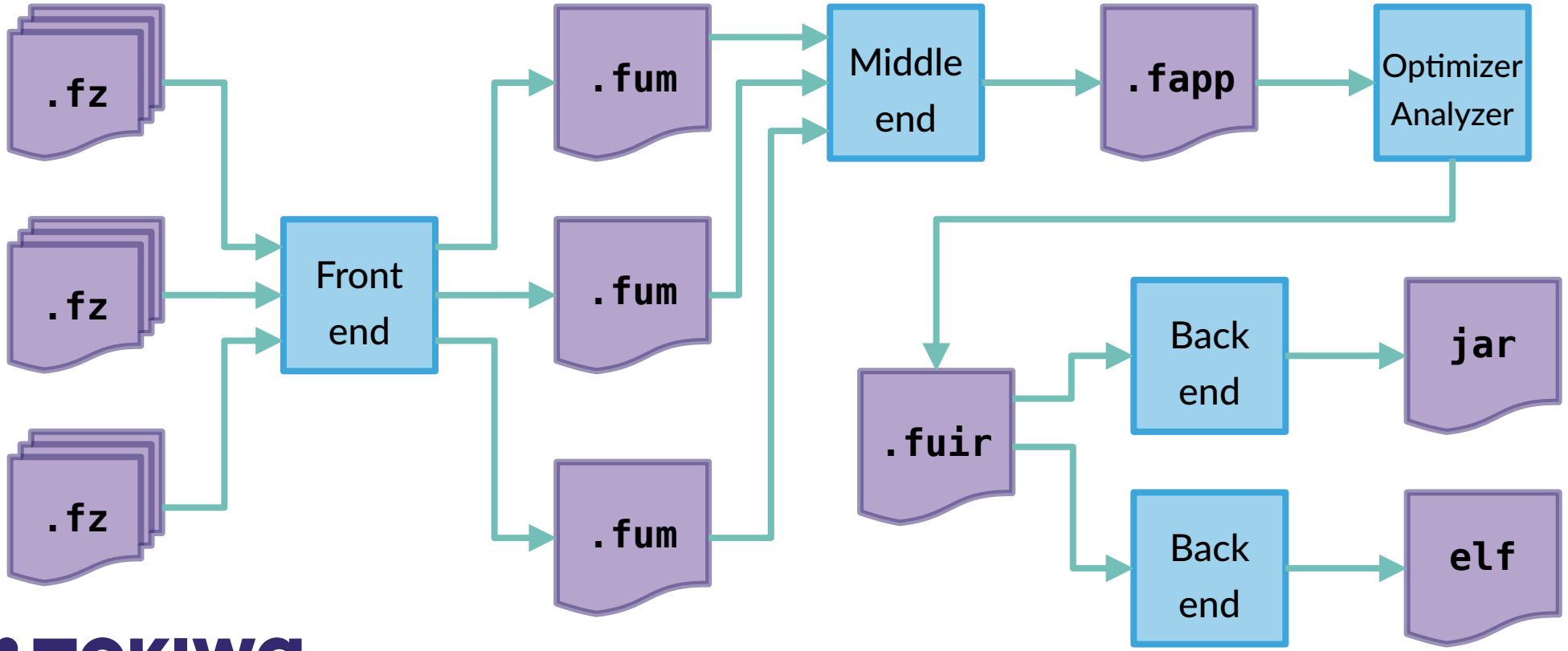


Fuzion Toolchain Design



Static Analysis In Fuzion Toolchain

Static analysis currently mostly non-existant.

Will be added to

- ➡ Front End
- ➡ Middle End
- ➡ Optimizer/Analyzer

Analysis Facilitated by Simple IR

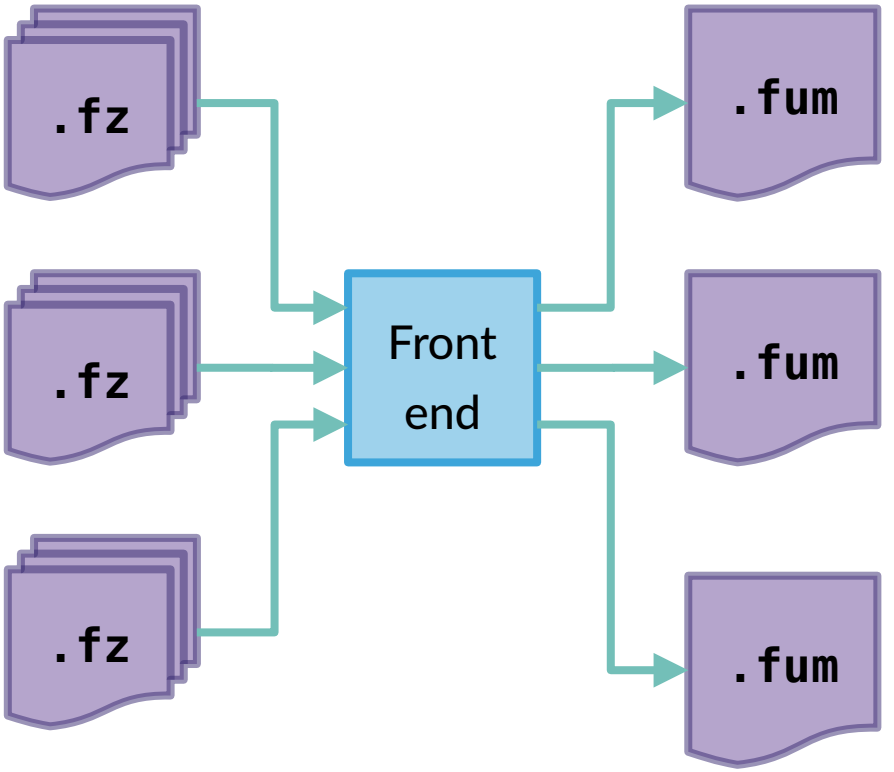
Fuzion Module files contain

- ➡ Features
  - five kinds: **routine**, **field**, **intrinsic**, **abstract** or **choice**
  - contain name, code, types, inner features
- ➡ Types are **feature types** or **type parameters**
- ➡ Code: 10 expressions: **call**, **match**, **const**, **assign**, **pop**, ...
  - no loops, no gotos

Static Analysis in Front End

Analyze single module

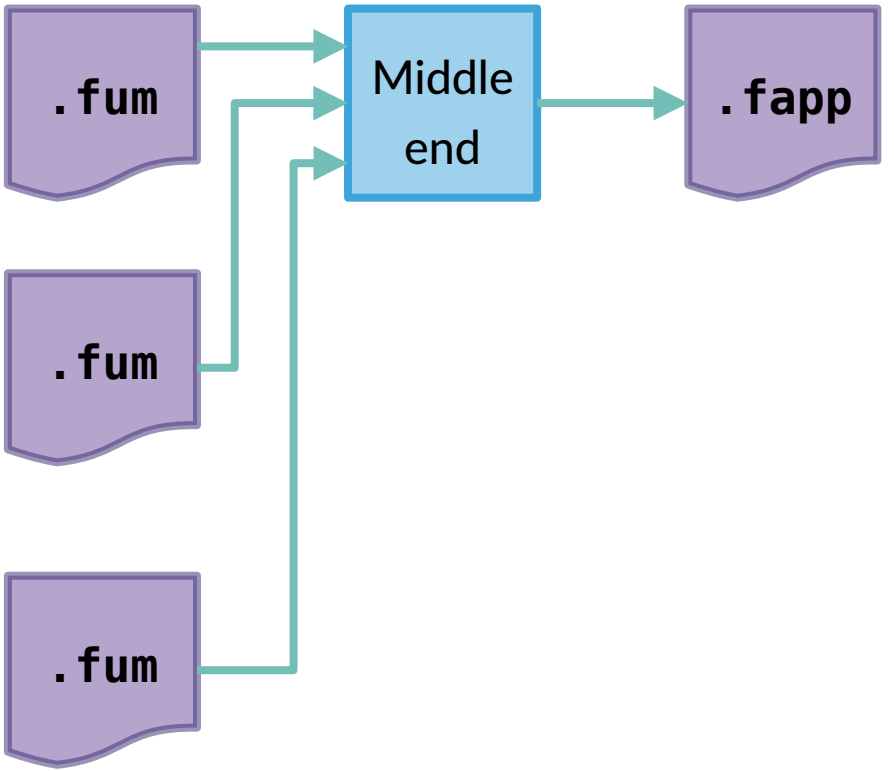
- ➡ Type Checking
- ➡ Init-before-use
- ➡ Immutability when escaped
- ➡ Thread safety



Static Analysis in Middle End

Analyze whole application

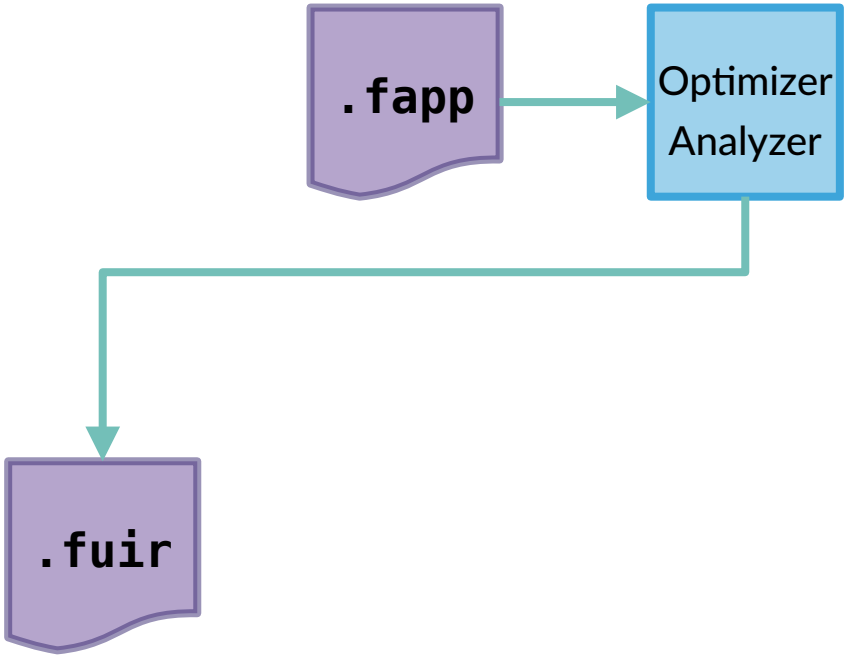
- ➡ Dead code removal
- ➡ Code Specialization
- ➡ Thread local data detection



Static Analysis in Optimizer/Analyzer

Analyze whole application

- ➡ Compile-time evaluation
- ➡ Code Specialization
- ➡ Call-graph analysis
- ➡ Lifespan analysis
  - stack vs. heap allocation
- ➡ Program-wide data flow



Fuzion: Next Steps

Development Plan

- ➡ intermediate files: .fum, .fapp, .fuir
- ➡ simple analysis tools: field init, immutability
- ➡ C back-end: GC, floats, etc.
  - interfacing C library code
- ➡ Standard Library
- ➡ Modeling I/O, thread communication and immutability
  - using automatic monadic lifting?

Conclusion

Fuzion is an exciting new language for safety

- ➡ simplicity
- ➡ design-by-contract
- ➡ prepared for static analysis
- ➡ we need
  - to grow our team
  - get developer feedback
  - secure long-term funding
- ➡ please get involved!

http://flang.dev

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github.com/tokiwa-software/fuzion

TOKIWA software