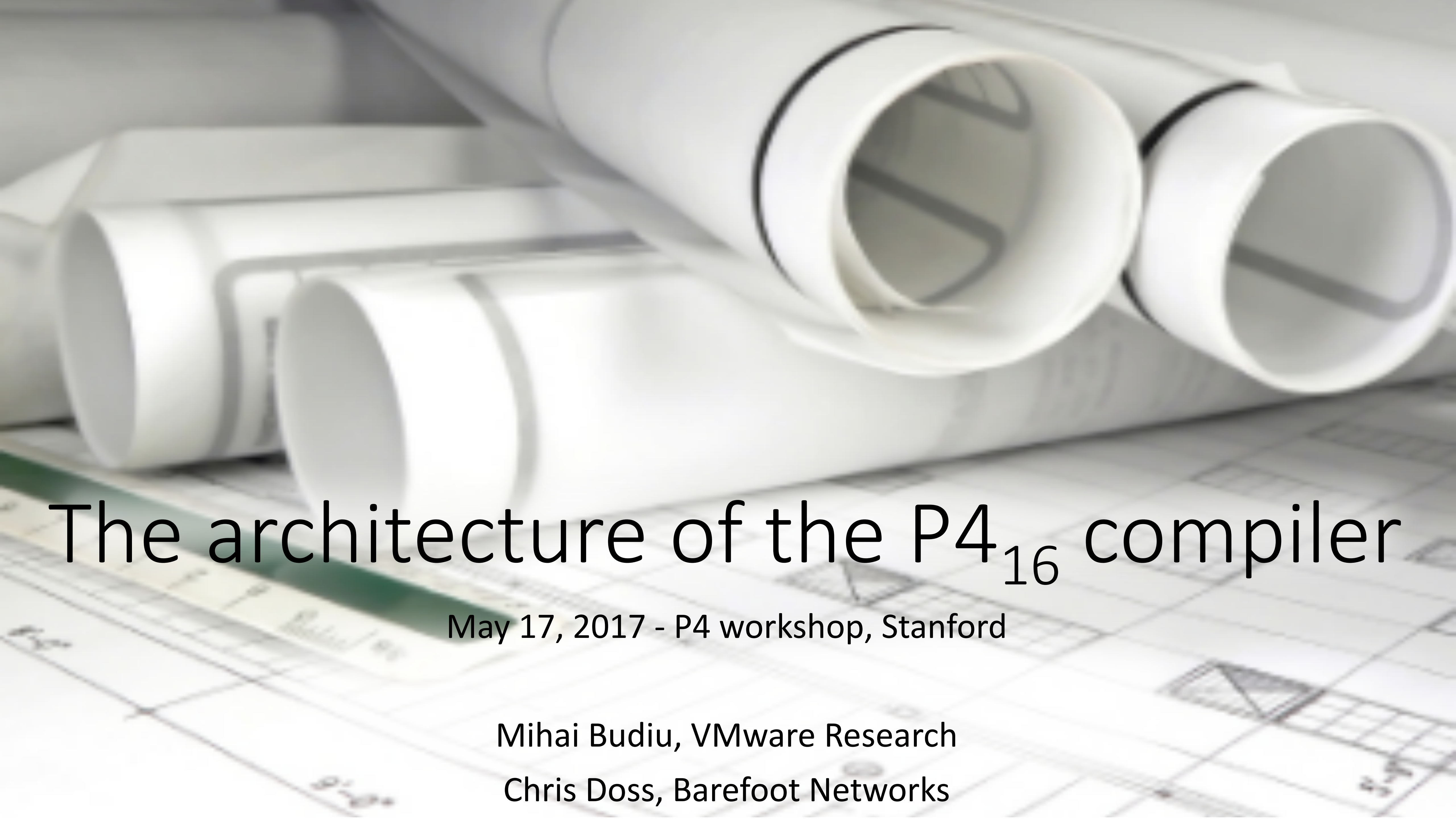

# The architecture of the P4$_{16}$ compiler

May 17, 2017 - P4 workshop, Stanford

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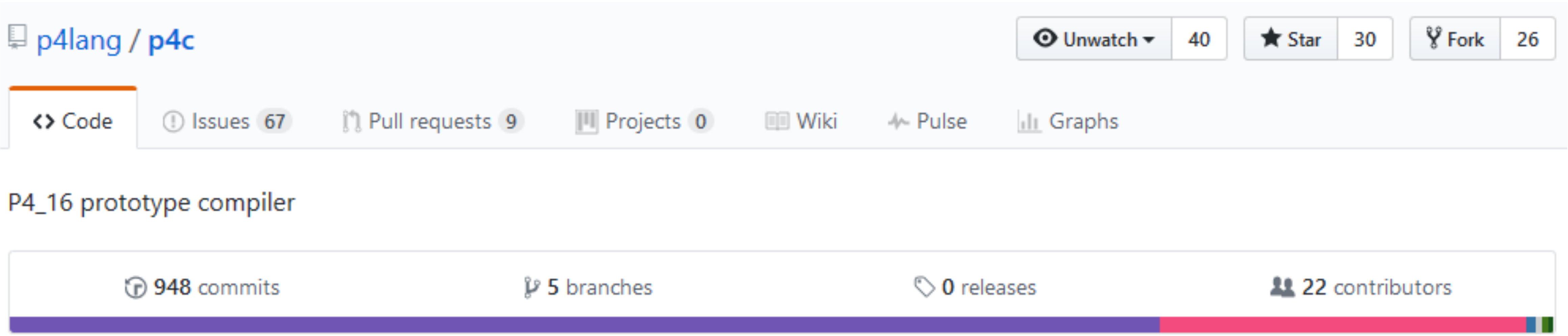
# P4$_{16}$

NEW

- Newest version of the P4 language (finalized yesterday!) https://github.com/p4lang/p4-spec/tree/master/p4-16/spec
- This talk is about the (reference implementation) compiler for P4$_{16}$
- Compiles both P4$_{14}$ (i.e., P4 v1.0 and P4 v1.1) and P4$_{16}$ programs
- Apache 2 license, open-source, reference implementation
- http://github.com/p4lang/p4c



p4lang / p4c

Unwatch 40 | Star 30 | Fork 26

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P4_16 prototype compiler

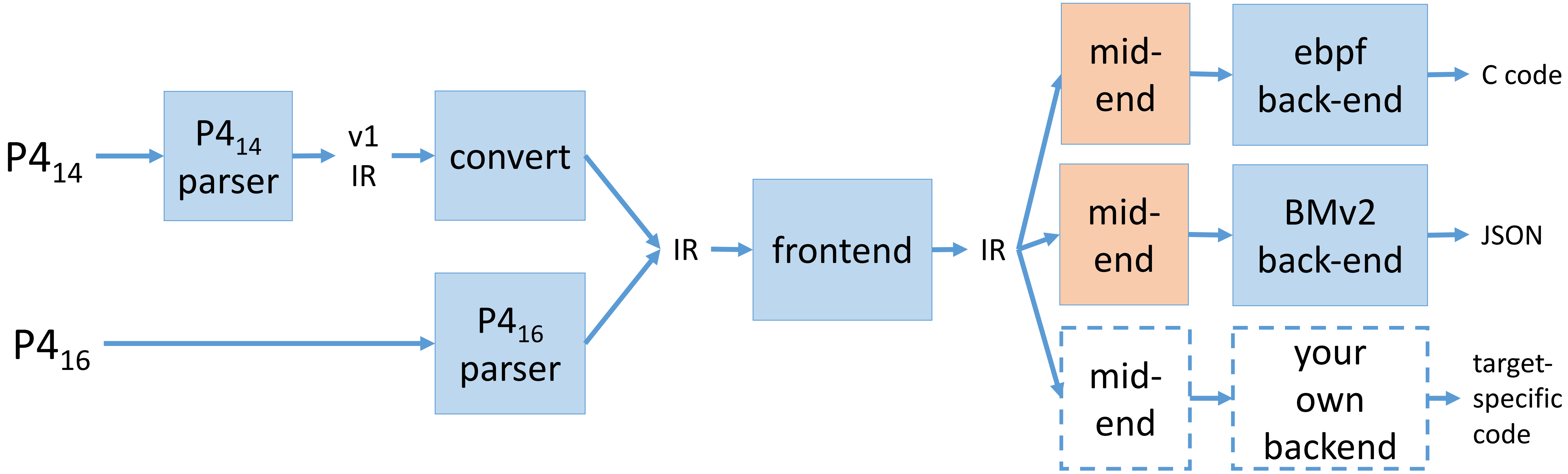
948 commits | 5 branches | 0 releases | 22 contributors

# Compiler goals

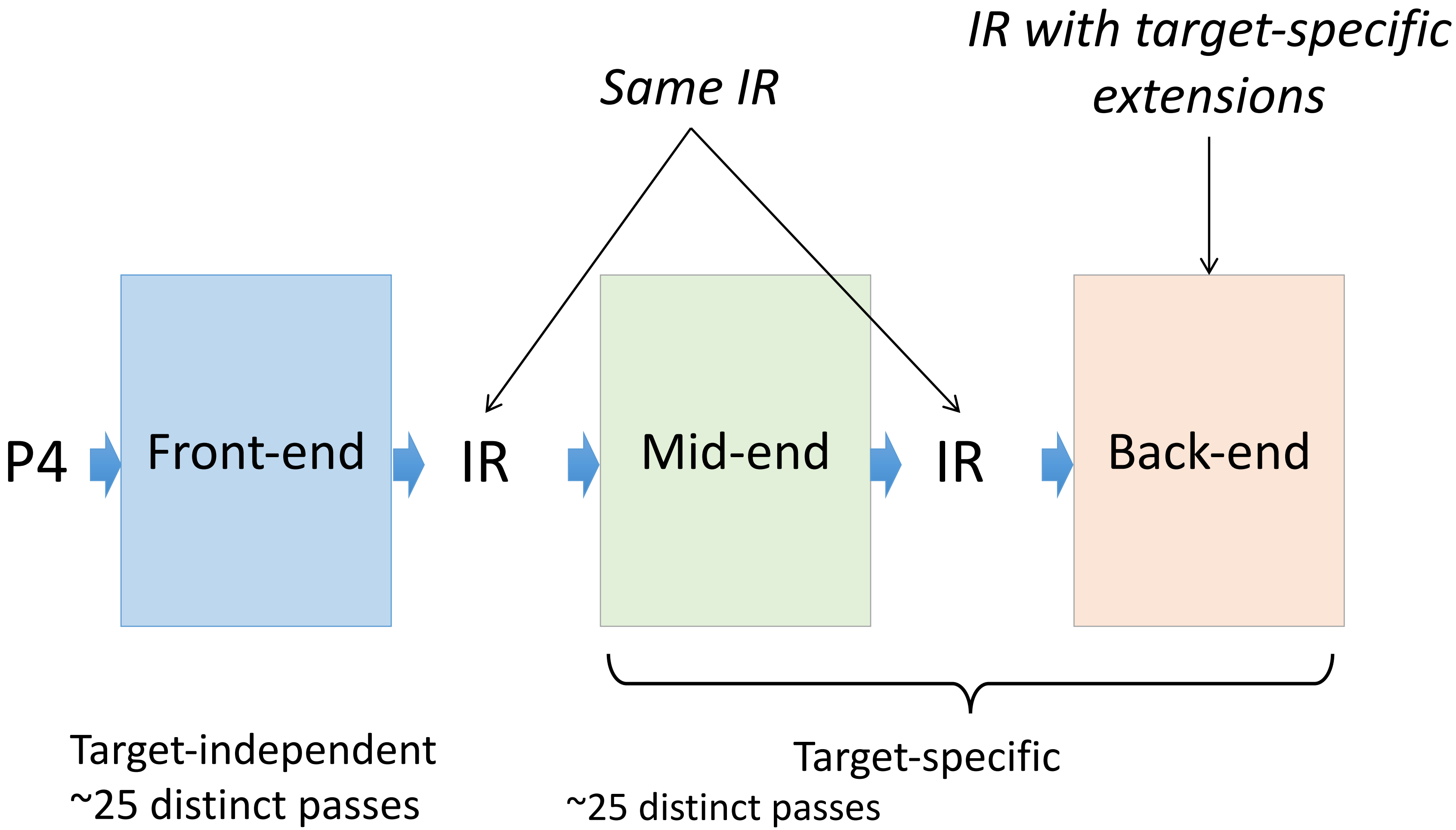
- Support current and future versions of P4
- Support multiple back-ends
  - Generate code for ASICs, NICs, FPGAs, software switches and other targets
- Provide support for other tools (debuggers, IDEs, control-plane, etc.)
- Open-source front-end
- Extensible architecture (easy to add new passes and optimizations)
- Use modern compiler techniques
  (immutable IR*, visitor patterns, strong type checking, etc.)
- Comprehensive testing

*IR = Intermediate Representation

# Compiler data flow



# Compiler structure



*Same IR*

*IR with target-specific extensions*

P4

Front-end

IR

Mid-end

IR

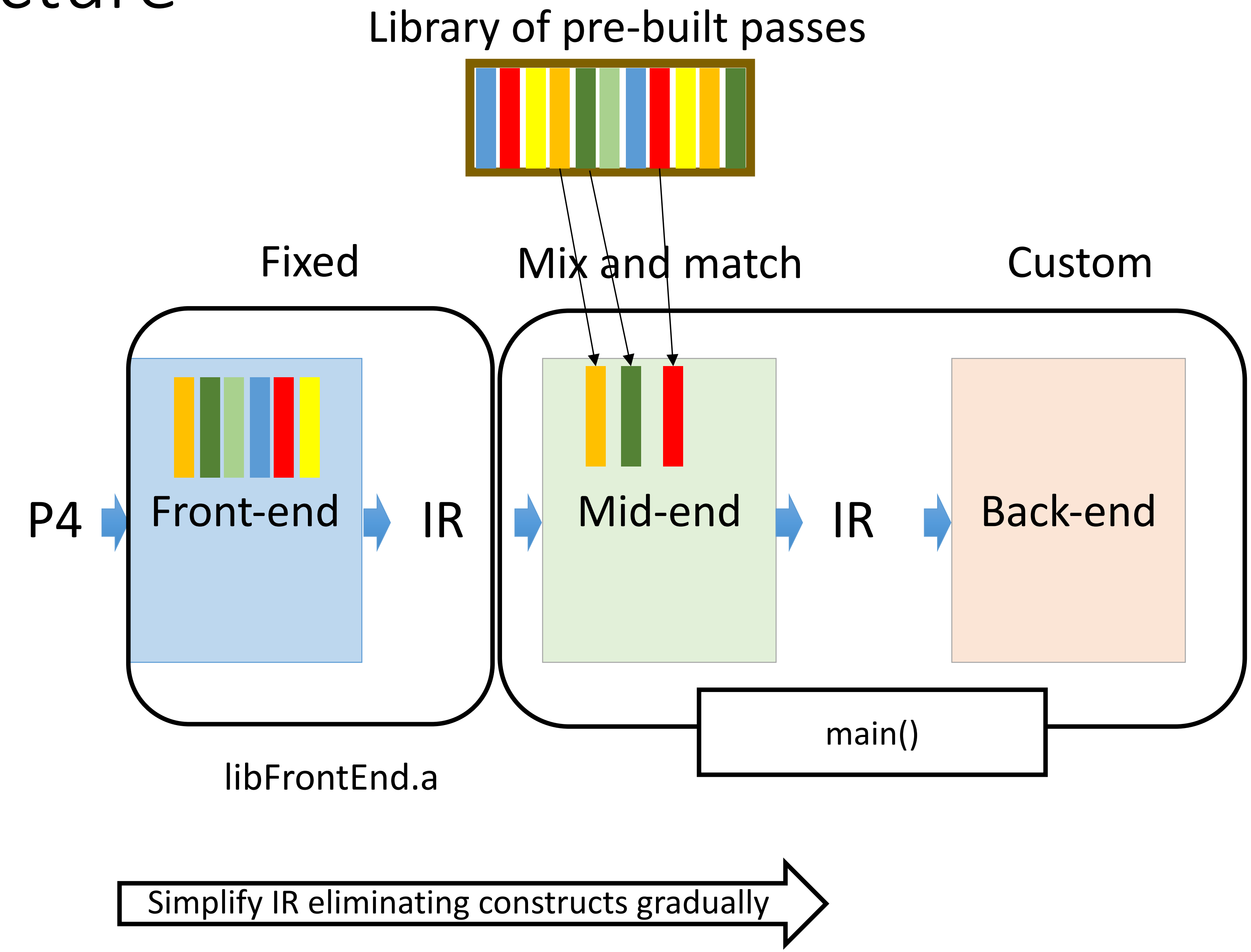
Back-end

Target-independent
~25 distinct passes

Target-specific

~25 distinct passes

# Structure

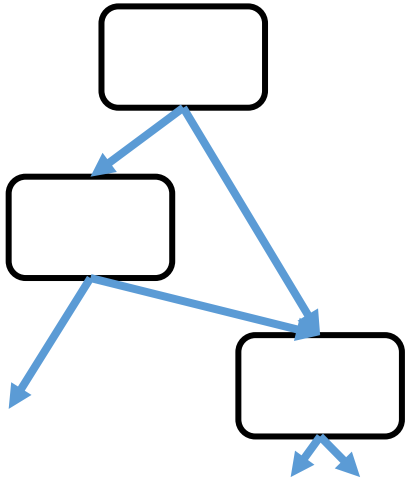

Library of pre-built passes
Fixed
Mix and match
Custom
P4
Front-end
IR
Mid-end
IR
Back-end
main()
libFrontEnd.a
Simplify IR eliminating constructs gradually

# Implementation details

- Common infrastructure for all compiler passes
  - Same IR and visitor base classes
  - Common utilities (error reporting, collections, strings, etc.)
- C++11, using garbage-collection (-lgc)
- Clean separation between front-end, mid-end and back-end
  - New mid+back-ends can be added easily
- IR can be extended (front-end and back-end may have different IRs)
- IR can be serialized to/from JSON
- Passes can be added easily

# Intermediate Representation (IR)

- Immutable
  - Can share IR objects safely
  - Even in a multi-threaded environment
  - You cannot corrupt someone else’s state
- Strongly-typed (hard to build incorrect programs)
- DAG structure, no parent pointers
- Manipulated by visitors
- IR class hierarchy is extensible



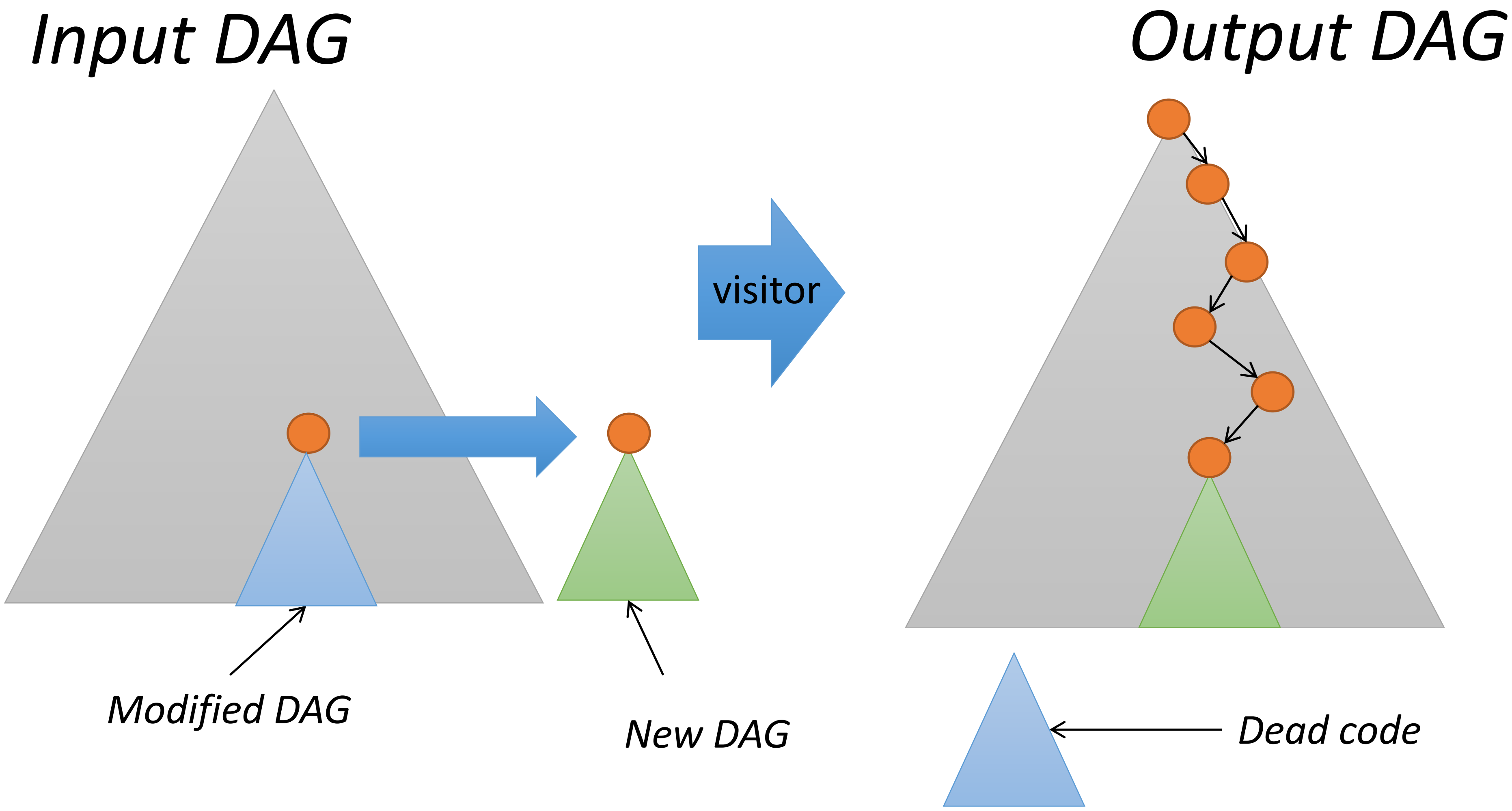
# Visitor pattern

- https://en.wikipedia.org/wiki/Visitor_pattern

  “In object-oriented programming and software engineering, the visitor design pattern is a way of separating an algorithm from an object structure on which it operates. A practical result of this separation is the ability to add new operations to existing object structures without modifying those structures.”

- “Structure” = IR
- “Algorithms” = program manipulations

# IR rewriting using visitors



# IR definition language compiled to C++

```
interface IDeclaration { … }

abstract Expression { … }

abstract Statement : StatOrDecl {}

class AssignmentStatement : Statement {
    Expression left;
    Expression right;
    print{ out << left << " = " << right; }
}
```

Class hierarchy

IR fields

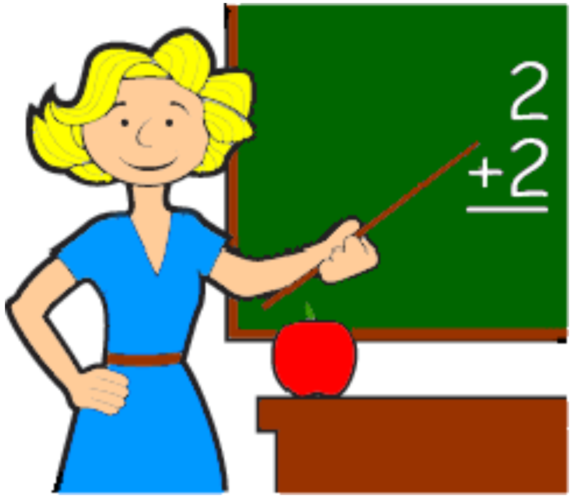
# IR ⟺ P4

- Front-end and mid-end maintain invariant that IR is always serializable to a P4 program
- Simplifies debugging and testing
  - Easy to read the IR: just generate and read P4
  - Easy to compare generated IR with reference (testing)
  - Compiler can self-validate (re-compile generated code)
  - Dumped P4 can contain IR representation as comments
- IR always maintains source-level position
  - can emit nice error message anywhere

# Learning the IR by example

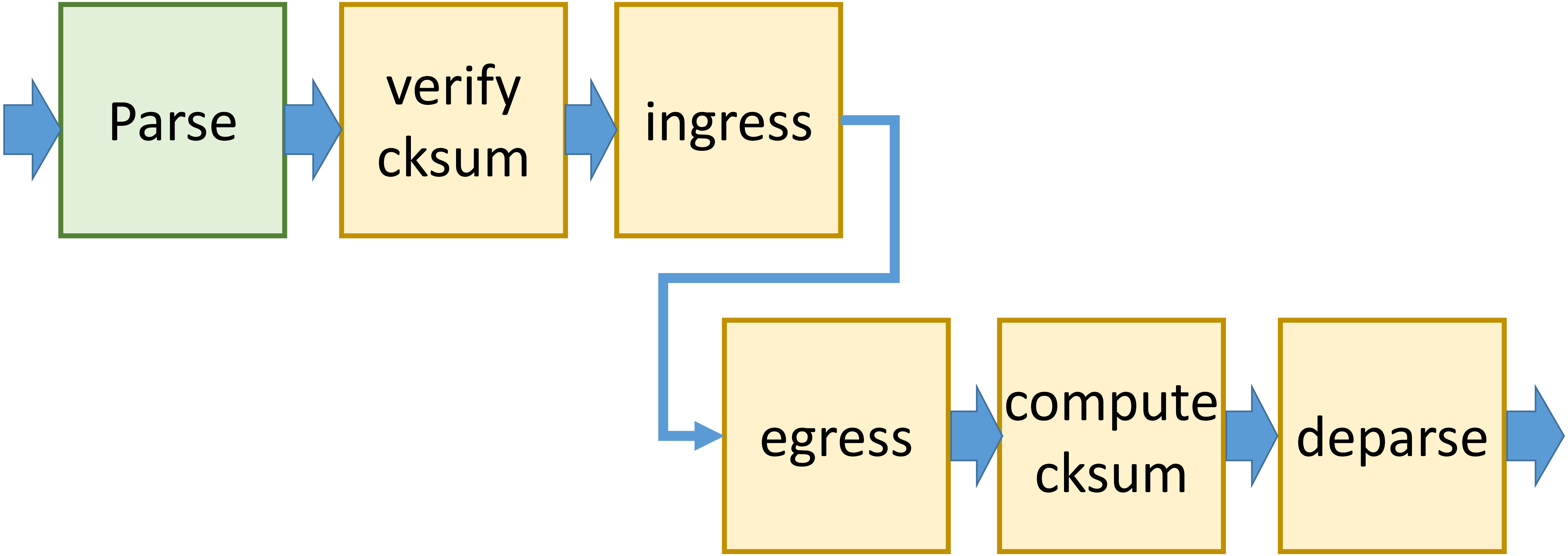
- *Front-end and mid-end passes can all dump IR back as P4 source with IR as comments*

```
/*
<P4Program>(18274)
  <IndexedVector<Node>>(18275) */
/*
  <Type_Struct>(15)struct Version */
struct Version {
/*
    <StructField>(10)major/0
      <Annotations>(2)
      <Type_Bits>(9)bit<8> */
        bit<8> major;
...
```



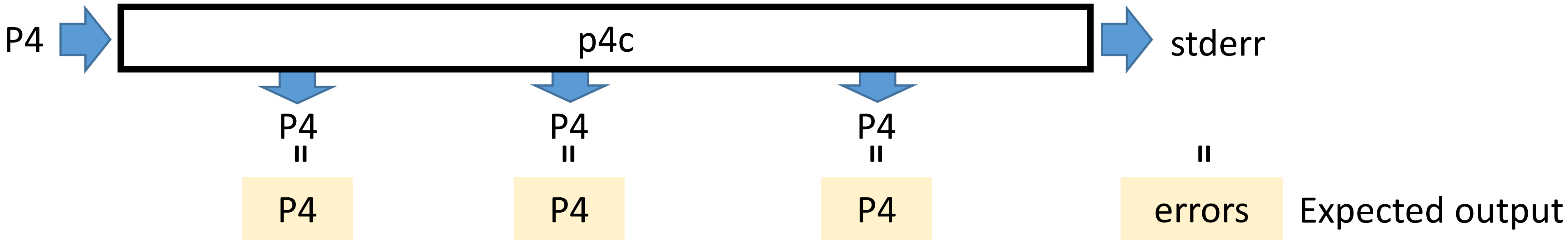
# v1model.p4: A $P4_{14}$ switch model

- A $P4_{16}$ switch architecture that models the fixed switch architecture from the $P4_{14}$ spec
- Provides backward compatibility for $P4_{14}$ programs



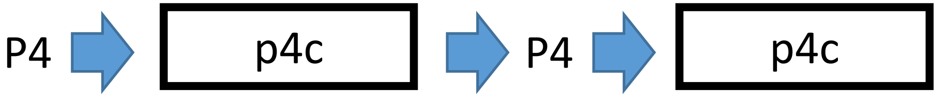
# Testing the compiler

- Dump program at various points and compare with reference
- Compare expected compiler error messages (on incorrect programs)



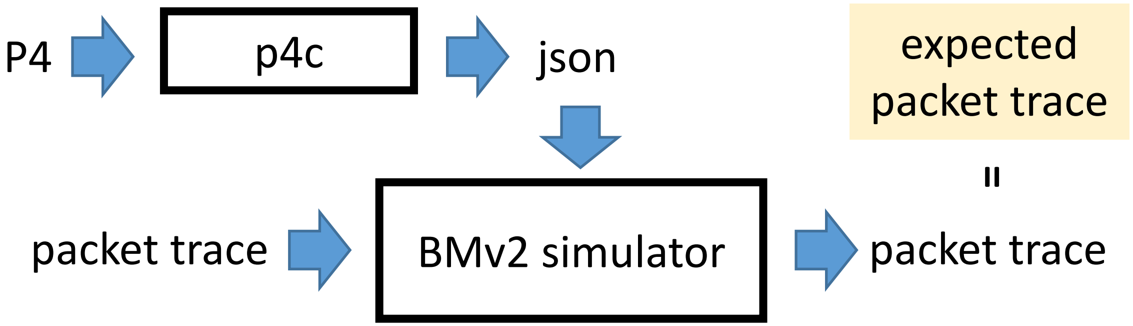
P4
p4c
stderr
P4 = P4
P4 = P4
P4 = P4
= errors
Expected output

- Recompile P4 generated by compiler



P4
p4c
P4
p4c

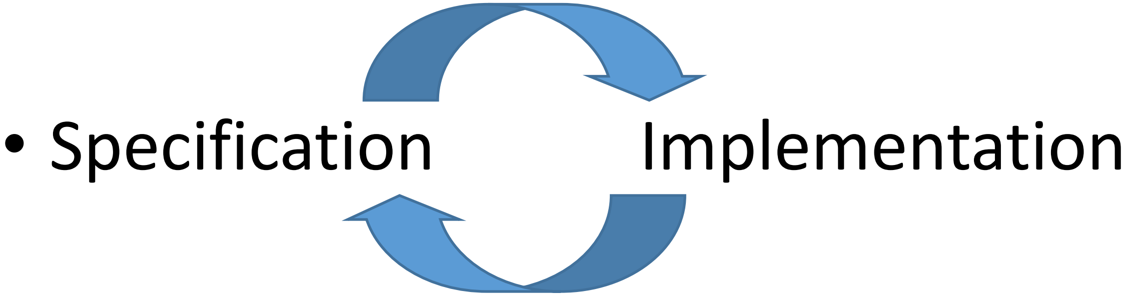
- Run v1model.p4 programs using BMv2 on packet traces and compare to expected output



P4
p4c
json
expected packet trace
=
packet trace
BMv2 simulator
packet trace

# Lessons

- P4$_{16}$ is a simple language,… but the P4 environment is complicated
  - Supports arbitrary architectures
  - Arbitrary functionality in the architecture
  - Arbitrary extensions (**extern** blocks)
- P4$_{16}$ is designed for extensibility
  - Compilers must support extensibility while preserving stability
- Modularity/extensibility seems to work
  - At least 5 existing back-ends, for software, simulators, FPGAs, ASICs



- Specification Implementation
- Great community: thank you all!