Executable Formal Semantic of $P4_{14}$ and Applications

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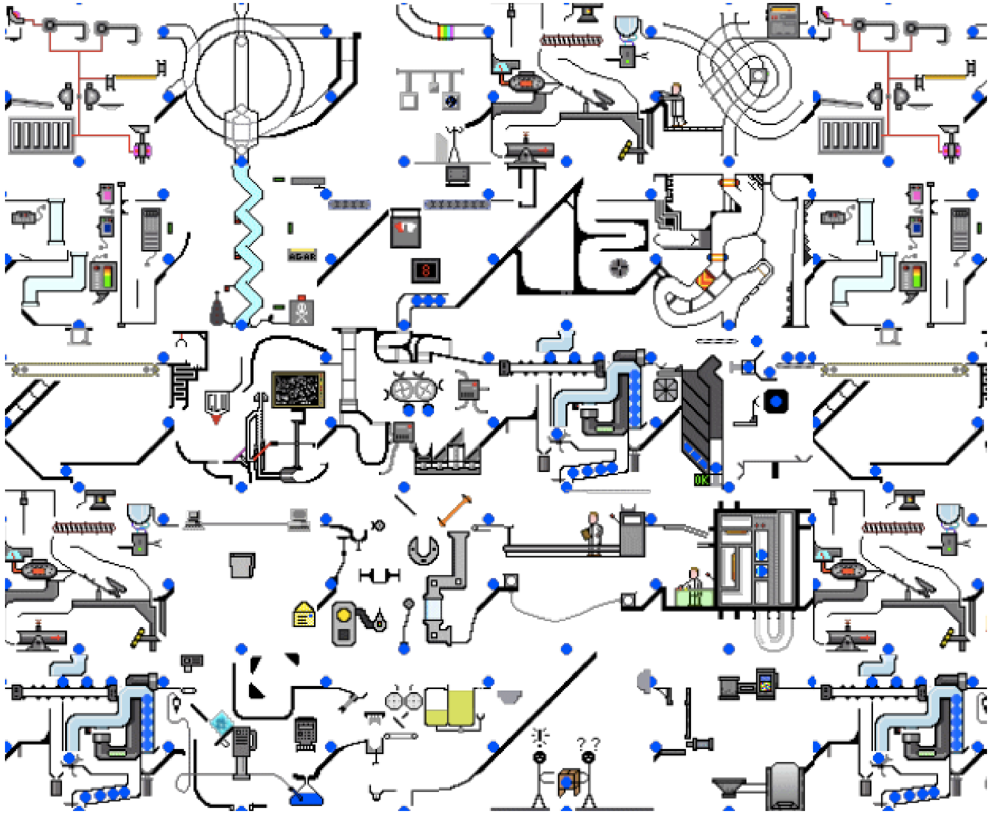
A need: Automated Verification



Complexity
(of networks and hardware)

+

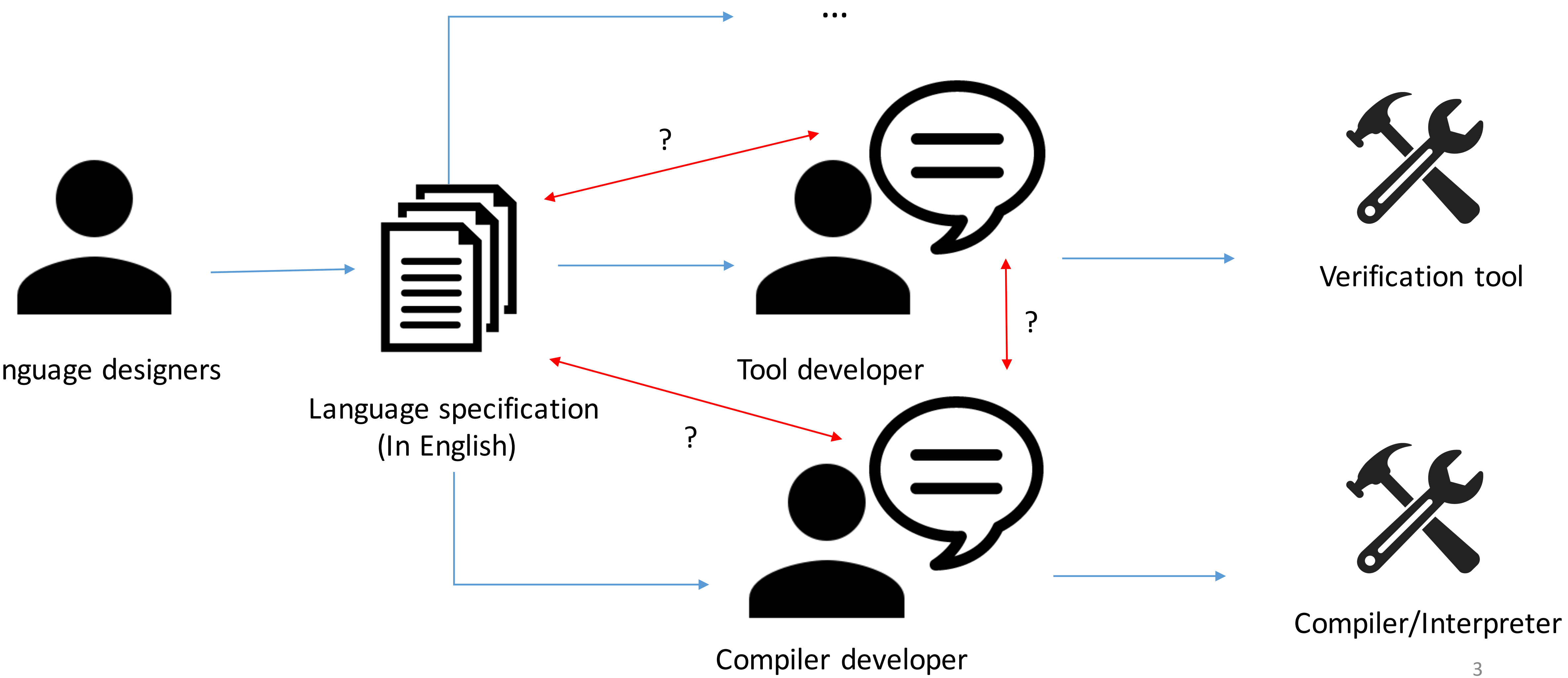
Flexibility and Agility
(of SDNs and P4)

→

(increased chance of)
Subtle Bugs

!

Current approach



Language designers

Language specification
(In English)

Tool developer

Compiler developer

Verification tool

Compiler/Interpreter

Formal semantics matter

Example from C language:

*

```
int main(void) {
  int x = 0;
  return (x = 1) + (x = 2);
}
```

GCC: 4
Clang: 3
Frama-C [Filliâtre et al]: 4
HAVOC [Lahiri et al] : 4
ISO C11: undefined

P4 Language Specification Version 1.0.3 (November 2, 2016):

“P4 assumes **parallel** semantics for the application of all the primitive actions executing as a result of a match in a given table. The execution of actions across different tables assumes **sequential** semantics where the sequence is determined by the control flow, described in Section 12.”

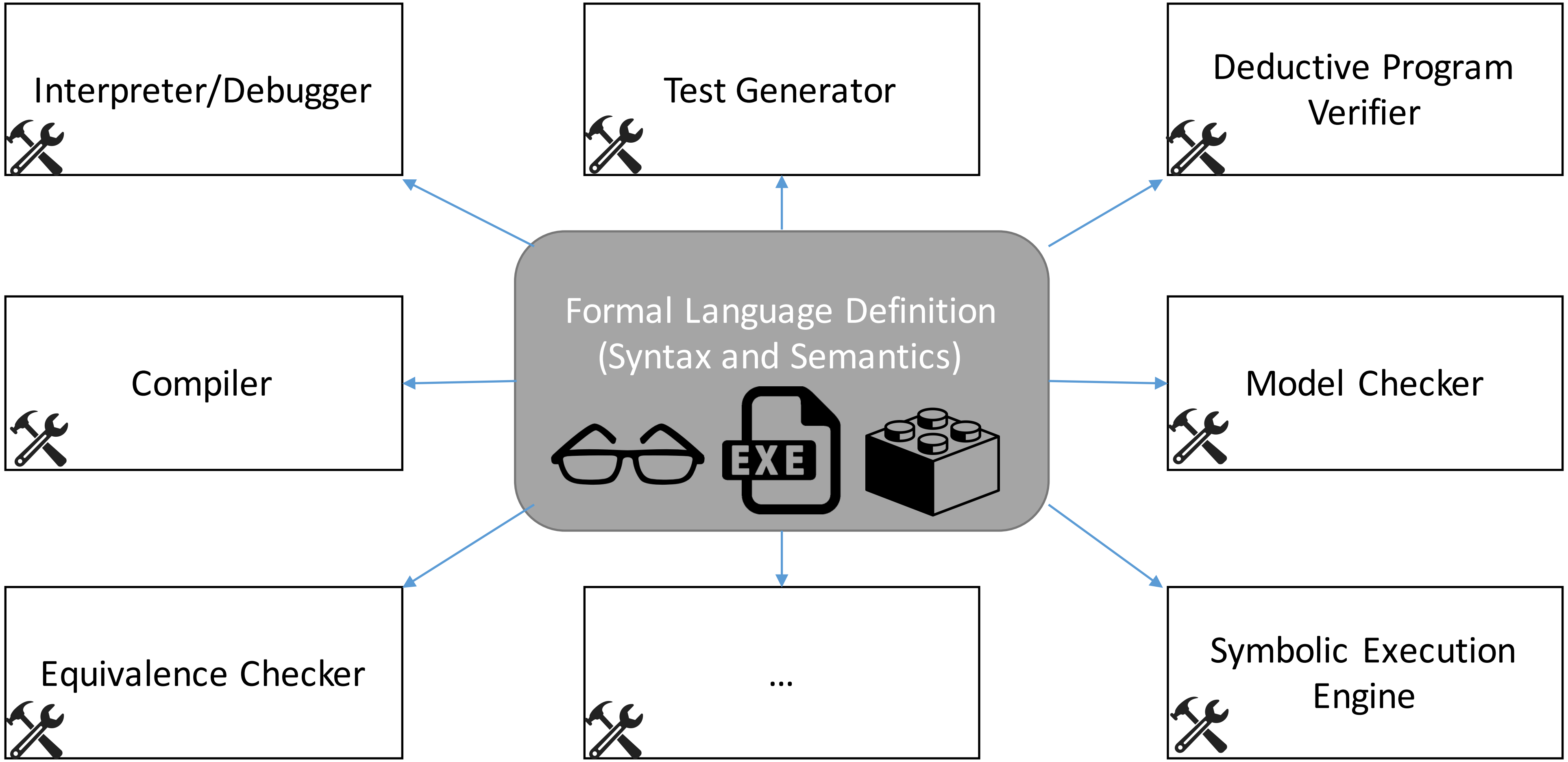
```
modify_field(hdr.fldA, 1);
modify_field(hdr.fldB, hdr.fldA);
```

```
modify_field(hdr.fldA, 1);
modify_field(hdr.fldA, 2);
```

?

* Rosu et al., http://www.kframework.org/index.php/K_Overview

Our vision



Interpreter/Debugger
Test Generator
Deductive Program Verifier
Compiler
Formal Language Definition (Syntax and Semantics)
EXE
Model Checker
Equivalence Checker
…
Symbolic Execution Engine

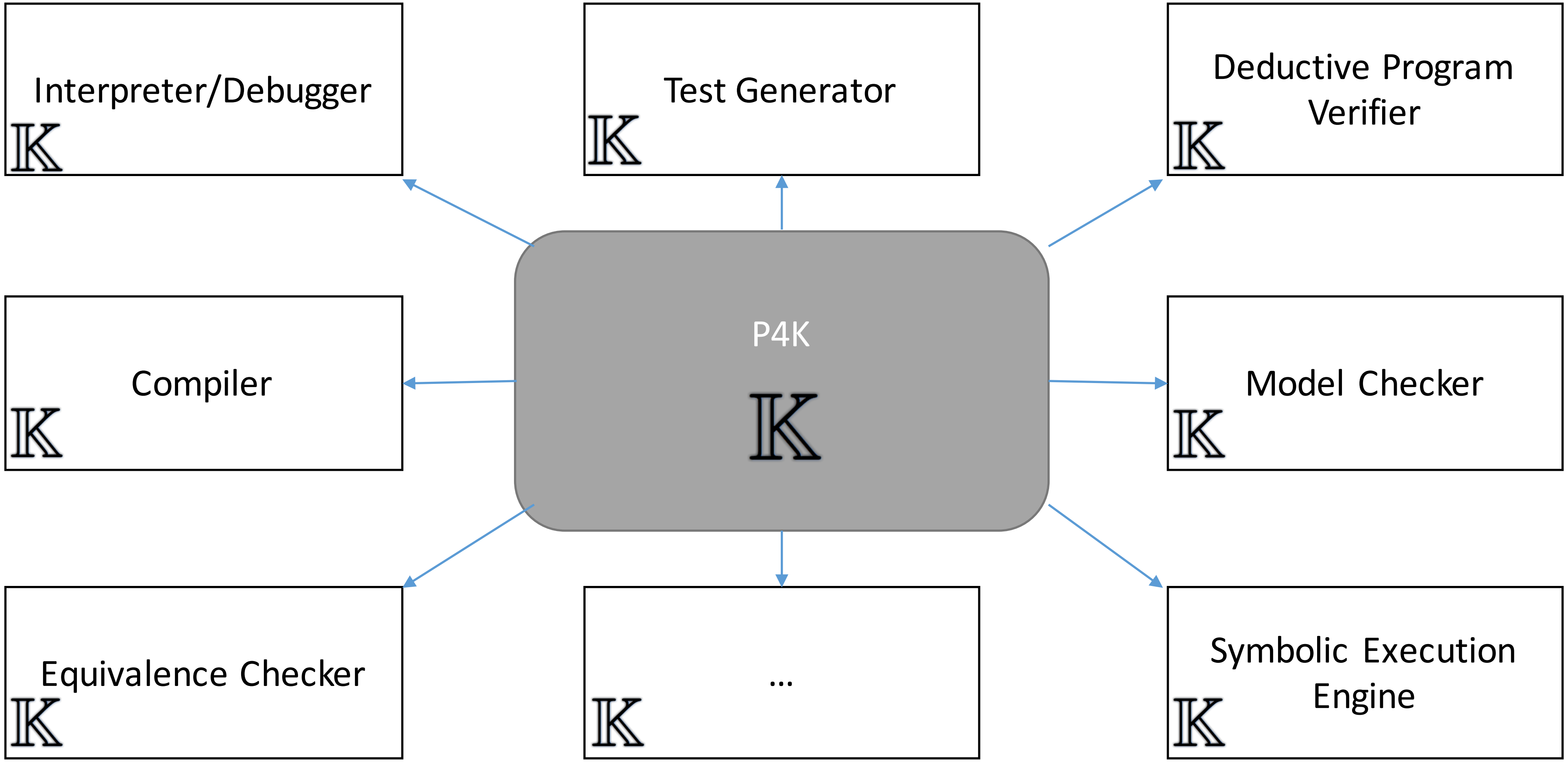
K Framework [Rosu et al, 2010]

- Rewrite-based programming language semantics engineering framework
    - Successfully used to give complete semantics to C, Java, JavaScript, …
- Semantics:
    - Configuration (state): nested cells
    - Rewrite rules (transitions): C[L_1 => R_1, … , L_n => R_n]

P4K: Semantics of P4$_{14}$ (V1.0.3) in K

- Not all features are currently supported
  - Enough rules to run simple P4 programs
  - e.g: *basic_routing* from p4factory
- Challenge: ambiguities and undefined behavior
    - Parallel semantics
    - Deparsing
    - Operands with different widths
    - …
  - More: https://github.com/kframework/p4-semantics/blob/master/issues.txt
  - Most addressed in P4$_{16}$

Tools (all for free!)



P4K

Interpreter/Debugger

Test Generator

Deductive Program Verifier

Compiler

Model Checker

Equivalence Checker

…

Symbolic Execution Engine

Potential App 1: Finding bugs using Symbolic Execution

- Property: Does the program either drop the packet or set the value of *egress_spec*? *
- Start with a **symbolic packet** $\langle ?\, P \rangle_{packet}$
- Search for a pattern in which neither the packet is dropped nor the *egress_spec* is set

* Nate Foster, personal communication

Potential App 1: Finding bugs using Symbolic Execution (cont.)

- Tested on *basic_routing*
- Found 2 type of inputs that lead to violation*:*
  - *P.ethernet.etherType != 0x0800*
  - *P.ipv4.dstAdr not in* ipv4_fib and ipv4_fib_lpm

```
parser parse_ethernet {
   extract(ethernet);
   return select(latest.etherType) {
      0x0800 : parse_ipv4;
      default: ingress;
   }
}
```

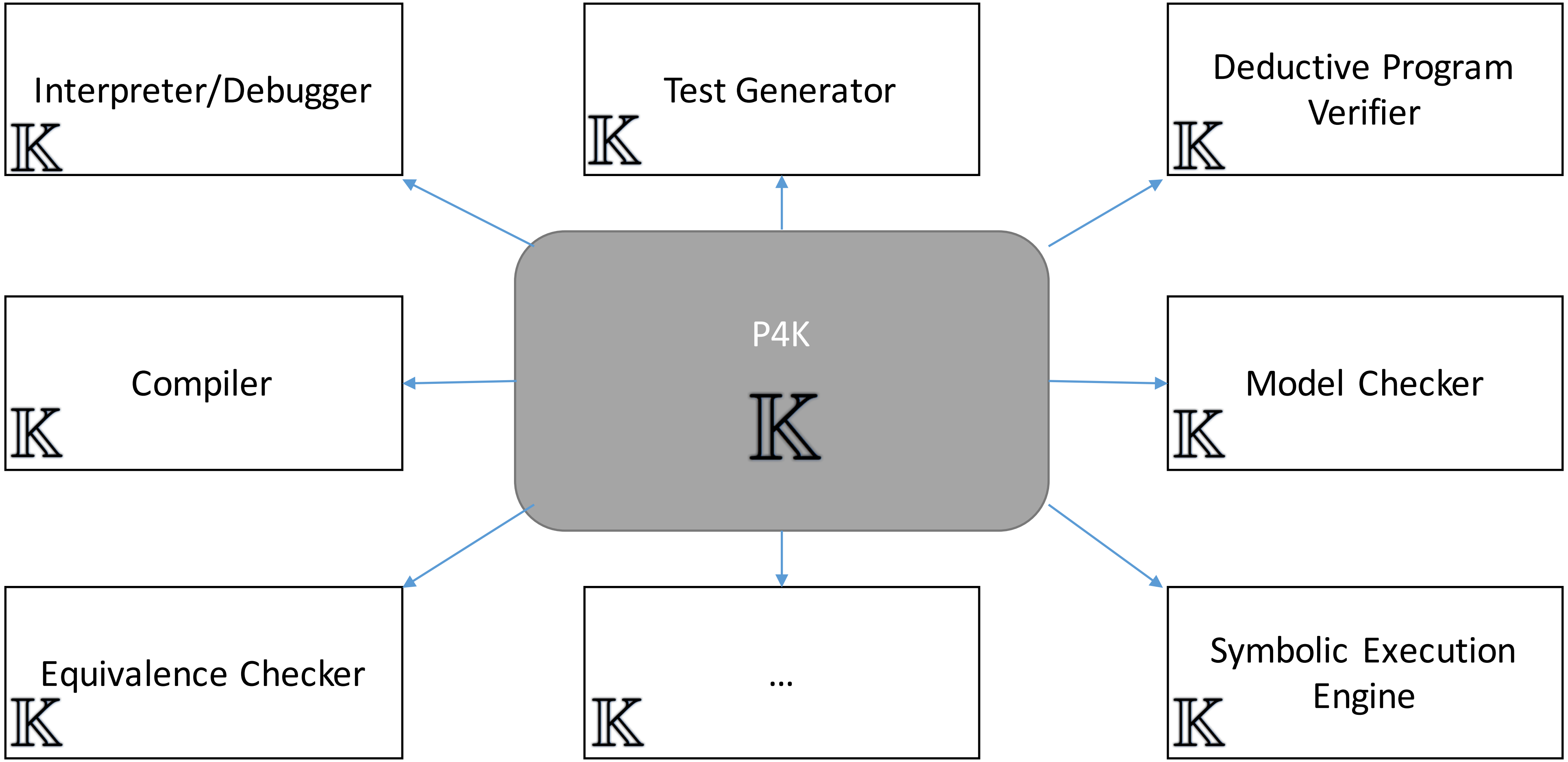
```
control ingress {
   if (valid(ipv4)) {
      …
   }
}
```

```
apply(ipv4_fib)  {
   on_miss {
      apply(ipv4_fib_lpm);
   }
}
```

Potential App 2: Data plane verification

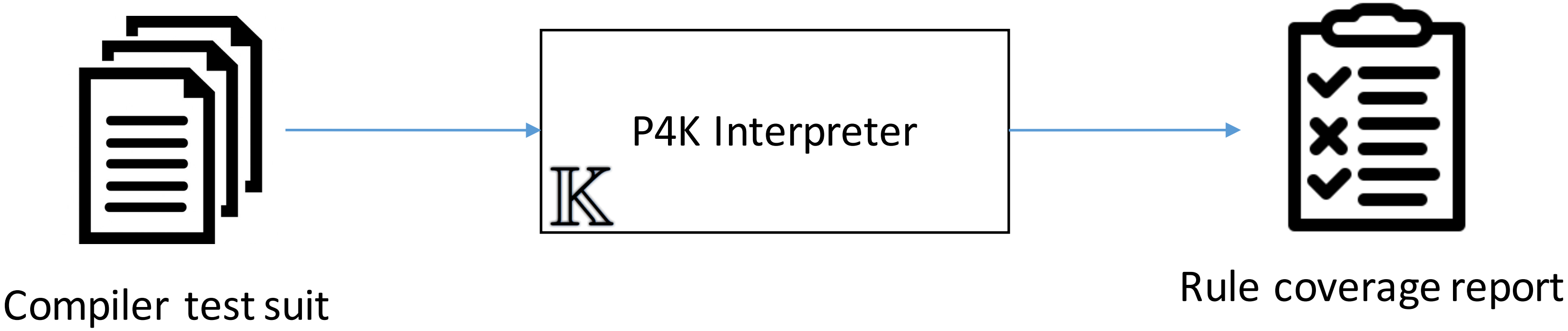
- Check network-wide reachability properties in data plane snapshot (for all packet headers)
  - E.g: Does all packets from A reach B?
  - HSA[Kazemian et al, NSDI’12], Veriflow[Khurshid et al, NSDI’13], Delta-net[NSDI’17], …
- Can be checked by inserting **symbolic packets** and using symbolic execution
- Need semantics of network
  - Easy to add

Tools (all for free!)



Potential App 3: Semantic coverage measurement

- “How much” of the language semantics is covered by the compiler tests suits?
- Similar technique for JavaScript ([Park et al, PLDI’15]) revealed:
  - **Inconsistencies** in JavaScript standard
  - **Bugs** in Web browsers



More Potential Apps

- Automatic conformance test generation
- Model checking
- Comprehensive network verification
  - by plugging controller programs written in C/Java/… without modifcation
- Equivalence check / translation validation
- Better language specification
  - Formalization itself might reveal problems in the specification
  - Use K rules in the language specification
    - or formalize the pseudo-code language
- [*insert ideas here*]

Conclusion

- Formal semantics matters
- P4K: Towards complete executable formal semantics of P4 in K
- Tools for P4 developers and designers based on the semantics
- Suggestion: Consider the framework for future versions of P4 language

- Check it out: https://github.com/kframework/p4-semantics/

p4workshop

- Learn more: http://www.kframework.org/
- Looking for ideas/collaborators
- Let’s get in touch: kheradm2@illinois.edu