Specifying, Testing and Verifying a Networked Server

From C to Interaction Trees

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Verification from RFCs to transistors

deep spec

Verified Software Toolchain

CERTIKOS

Kami

Application

OS

Hardware

01011…

One theorem to verify…

Quick Chick

… and test!

More projects at deepspec.org…

Towards a verified web server

deep spec server

Verified Software Toolchain

HTTP Server

CERTIKOS

OS

Kami

Hardware

QuickChick

01011...

Towards a verified web server

deep spec server

Verified Software Toolchain

CERTIKOS

Kami

Swap Server

OS

Hardware

Today: a simplified server

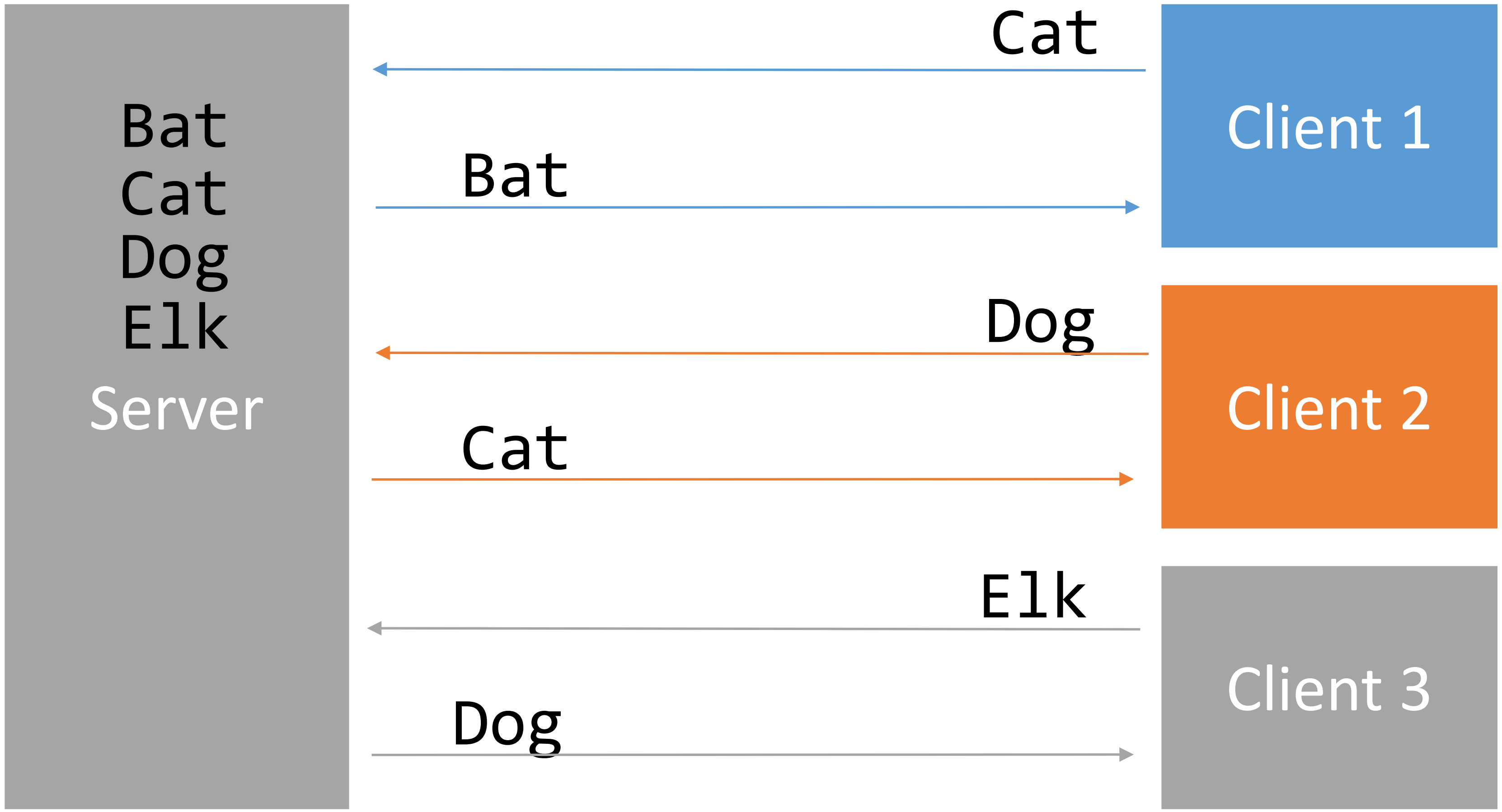
QuickChick

01011...

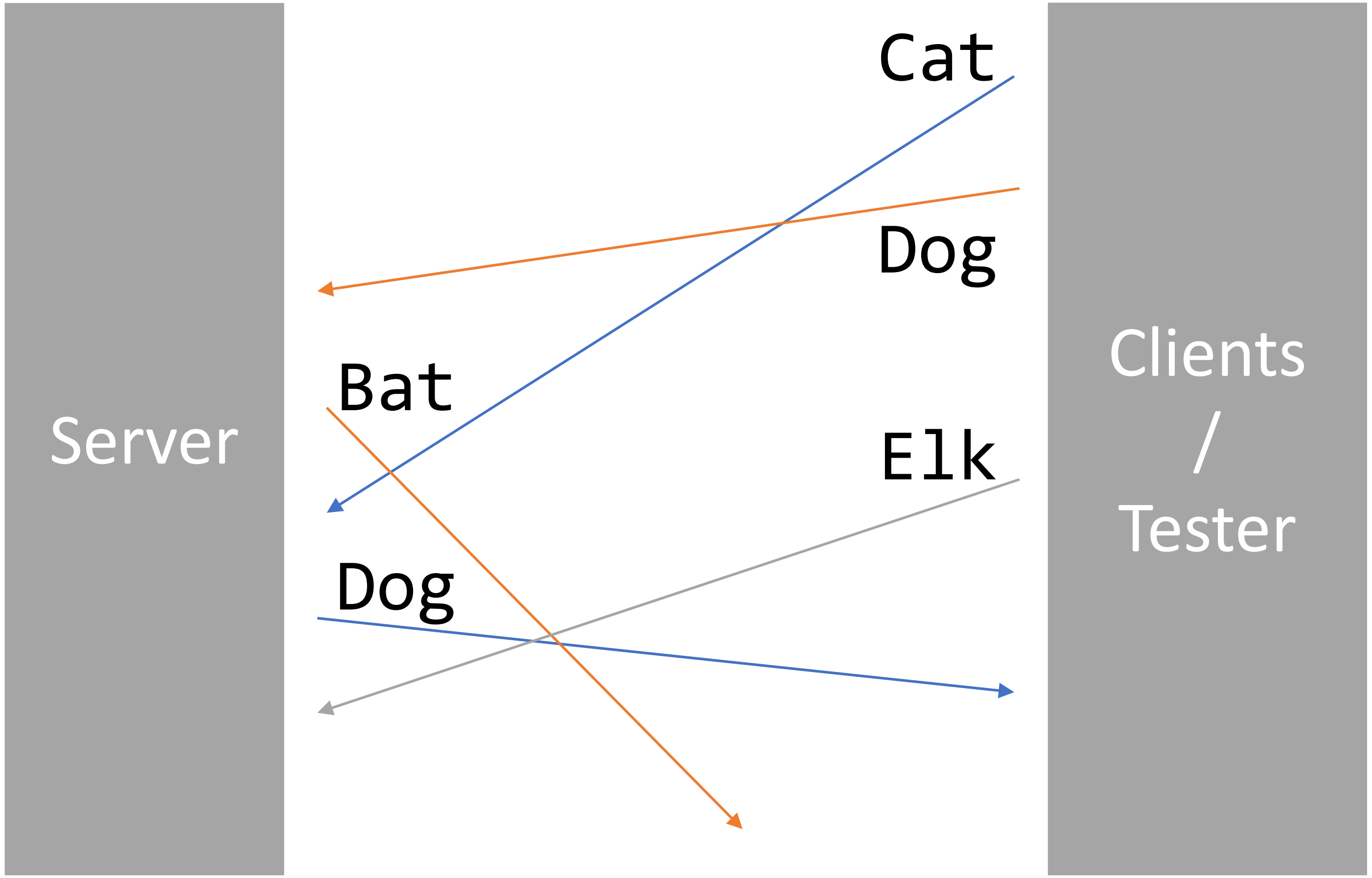
Main contributions

- Verifying a networked C program using VST, which can run in CertiKOS
- Specification describes what a client can observe *over the network*
- Testable specification, using QuickChick

Swap server specification

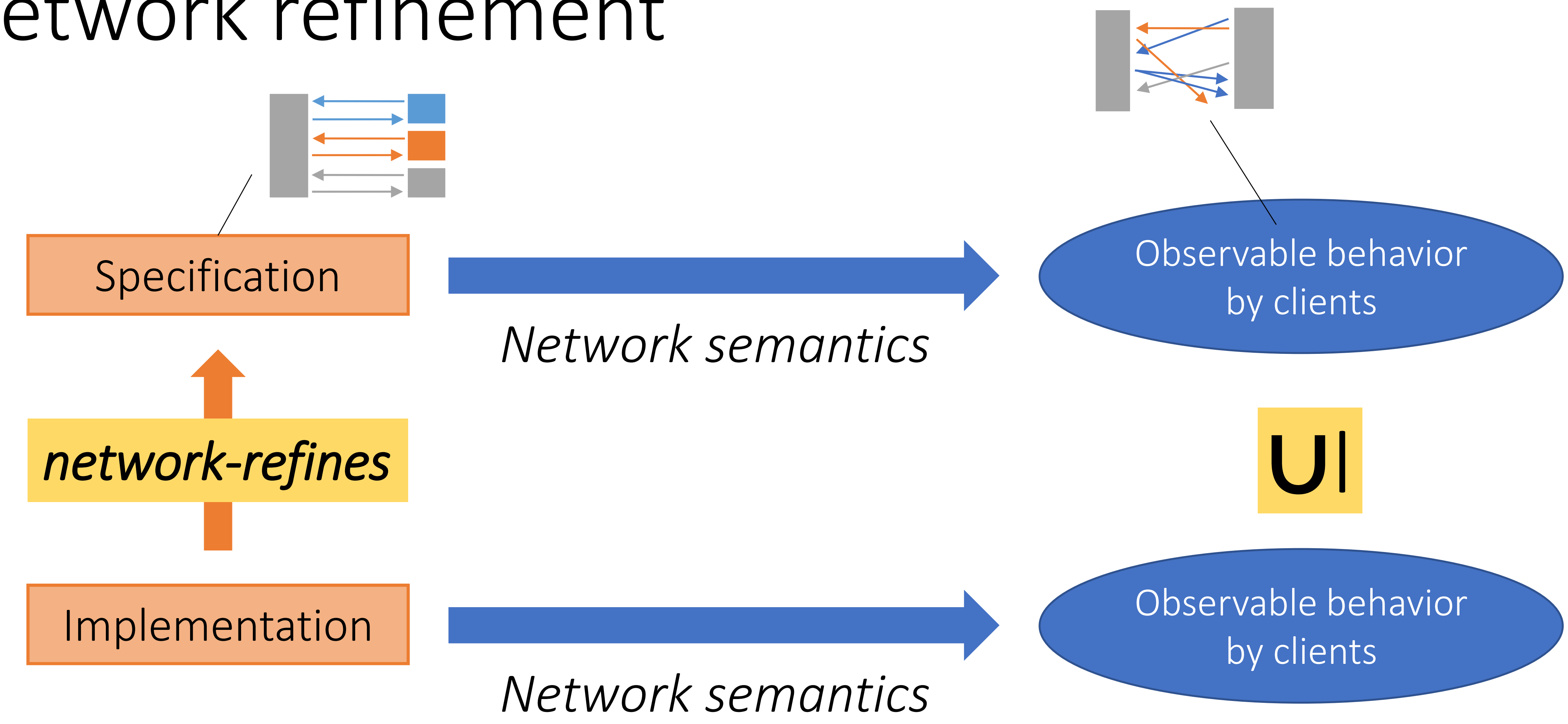


Swap server: in the real world



- Messages on different connections can be reordered
- Messages can be delayed indefinitely

Network refinement

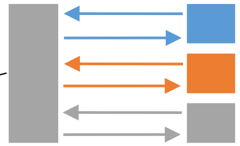


Adaptation of Observational refinement/Linearizability

*: concepts defined in the paper

Overview: proof architecture

*Specification**



Written in Coq

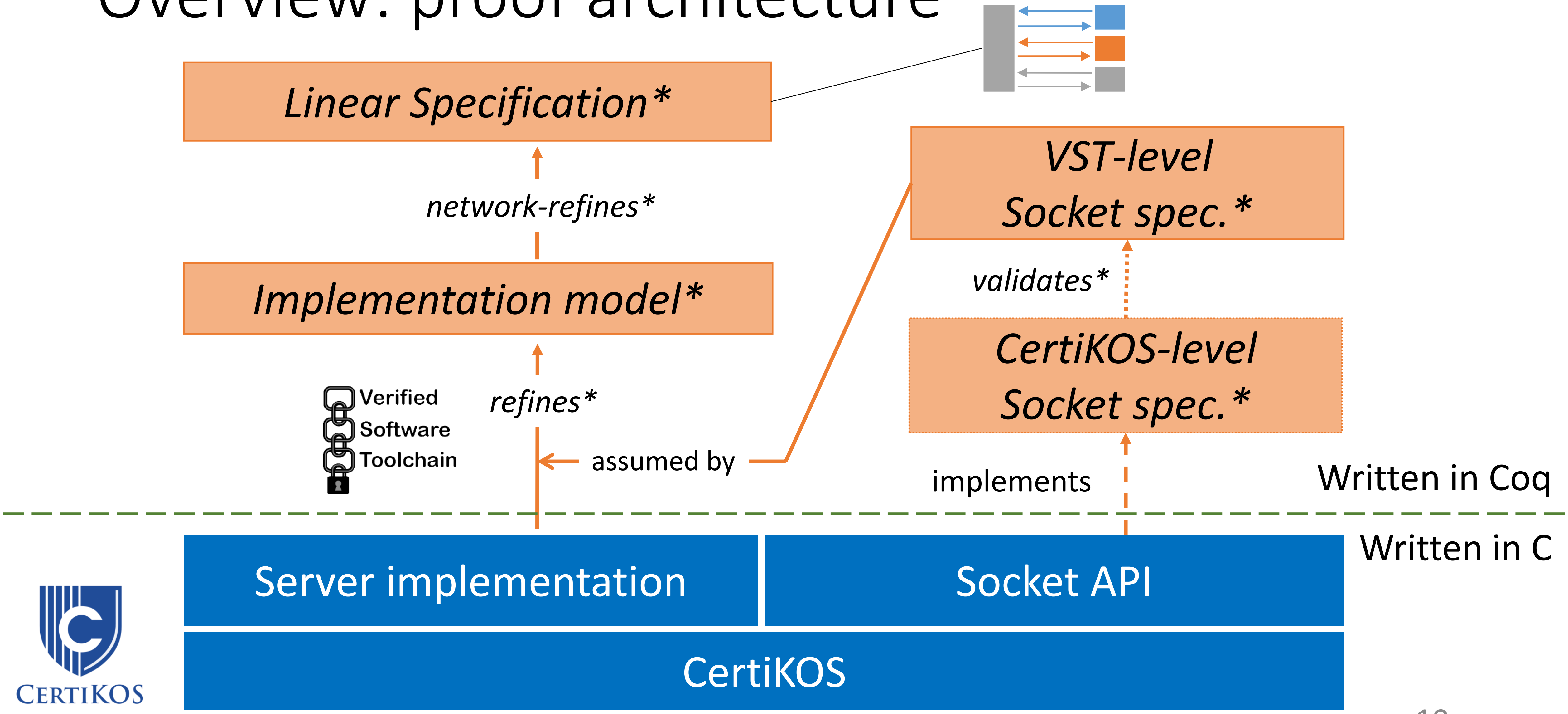
Written in C

Server implementation	Socket API
CertiKOS	

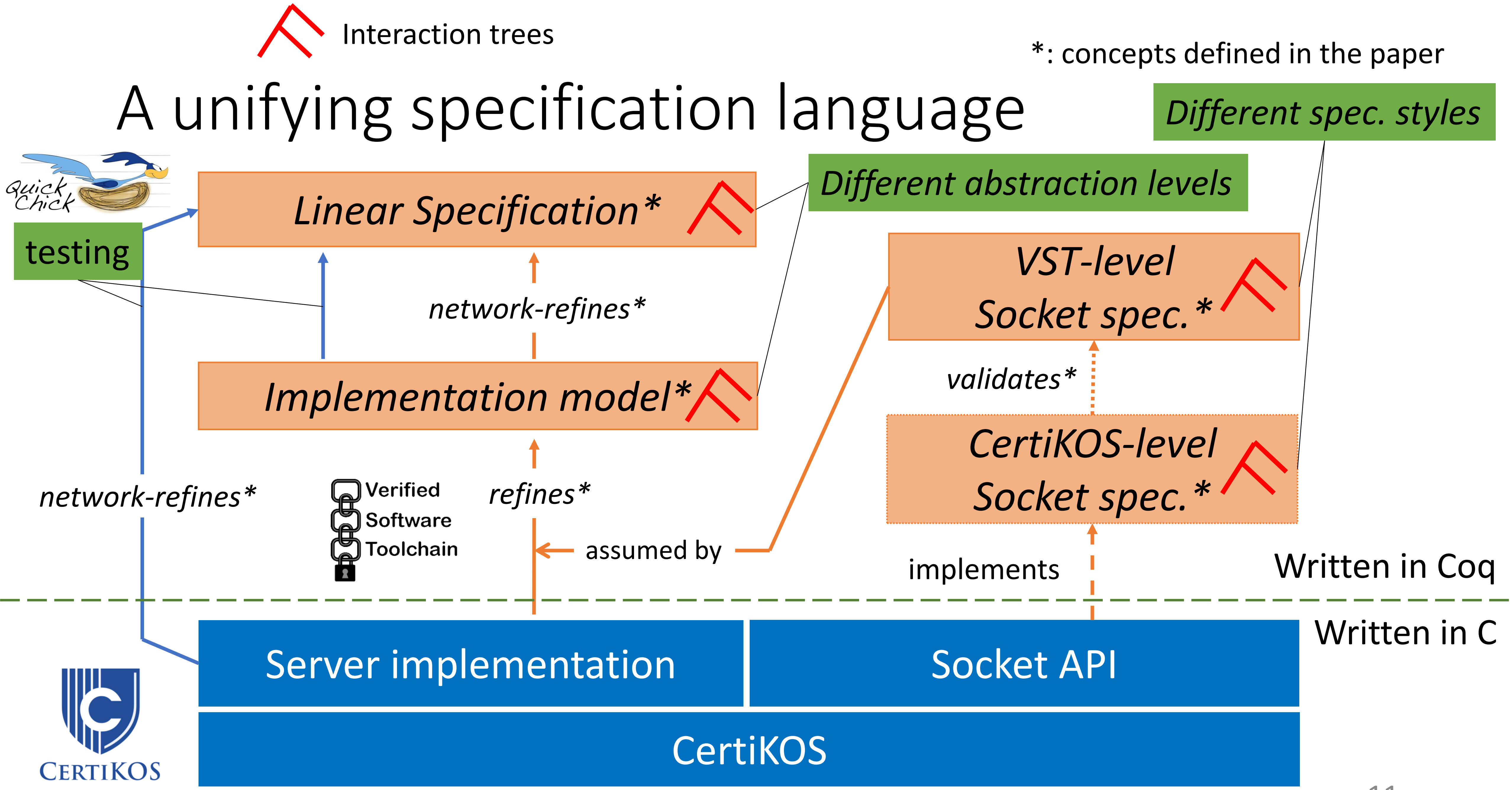
CertiKOS

*: concepts defined in the paper

Overview: proof architecture

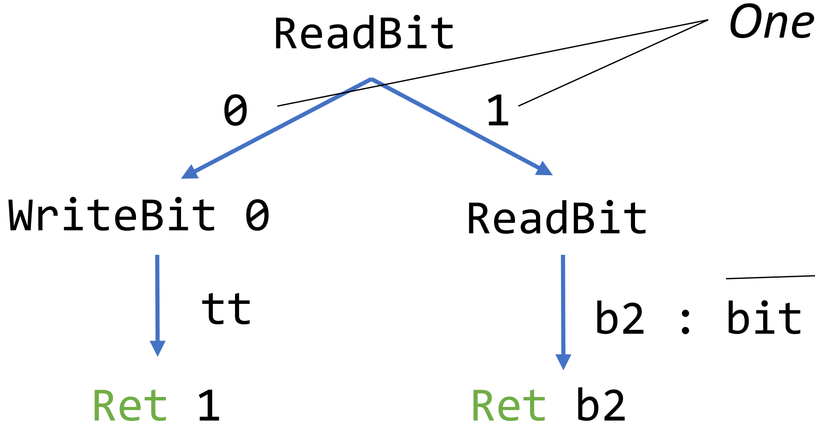


A unifying specification language



Interaction trees: example

(aka. Free monads)



One branch for each possible result

Shorthand notation for two or more branches

Type of effects ioE:

```
Inductive ioE : Type -> Type :=
| ReadBit  : ioE bit
| WriteBit : bit -> ioE unit
.
```

Result type

Interaction trees: definition

(aka. Free monads)

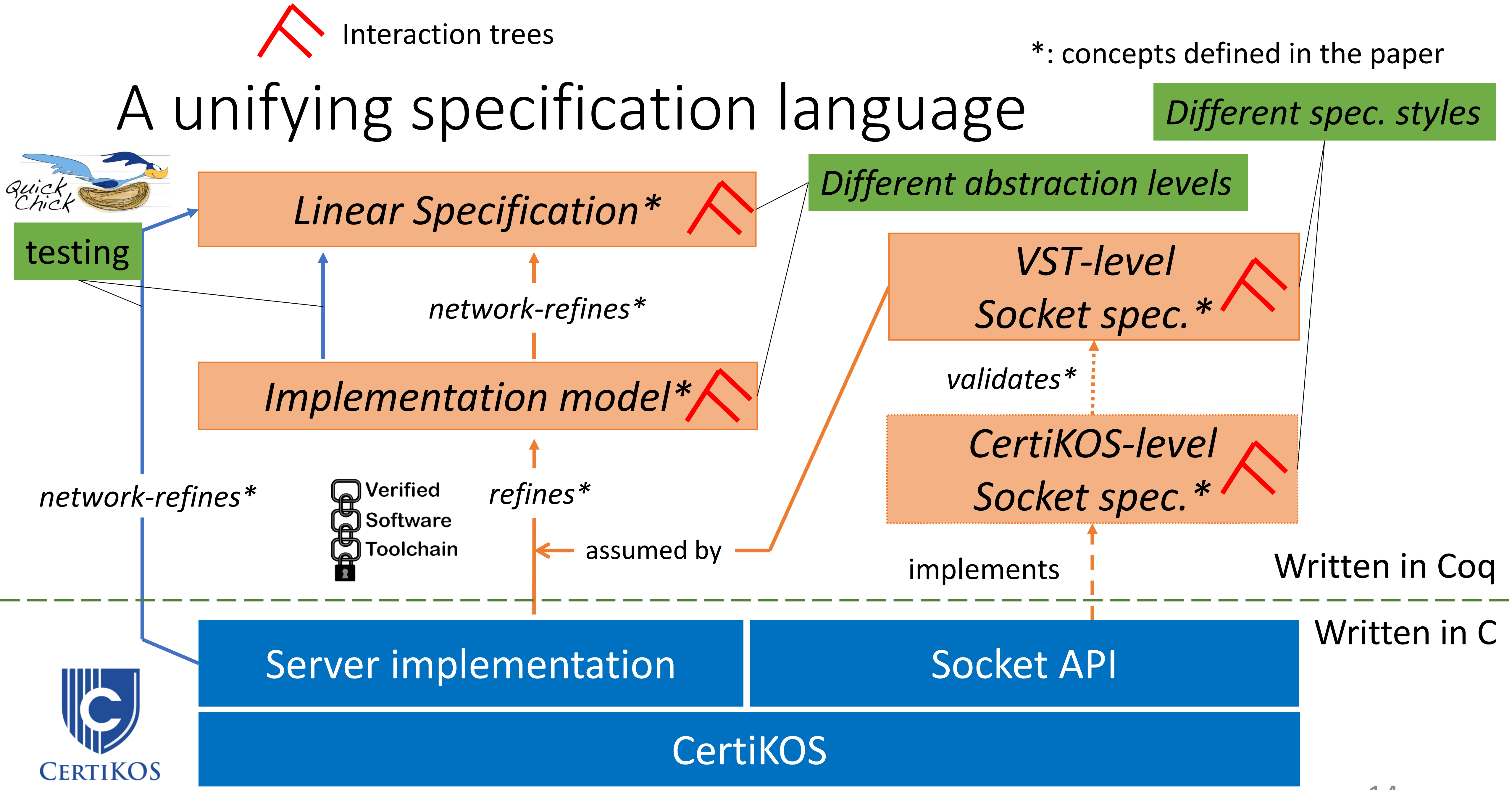
Type of effects (e.g., ioE)

Type of results

```
CoInductive itree (E : Type -> Type) (R : Type) :
Type :=
| Vis : ∀ Y, E Y -> (Y -> itree E R) -> itree E R
| Ret : R -> itree E R
| Tau : itree E R -> itree E R
.
```

Effect

Continuation


Interaction trees
*: concepts defined in the paper
A unifying specification language
Different spec. styles
Different abstraction levels
QuickChick
testing
Linear Specification*
network-refines*
Implementation model*
VST-level
Socket spec.*
validates*
CertiKOS-level
Socket spec.*
network-refines*
Verified
Software
Toolchain
refines*
assumed by
implements
Written in Coq
Written in C
Server implementation
Socket API
CertiKOS
CERTIKOS

The Swap server "linear specification"

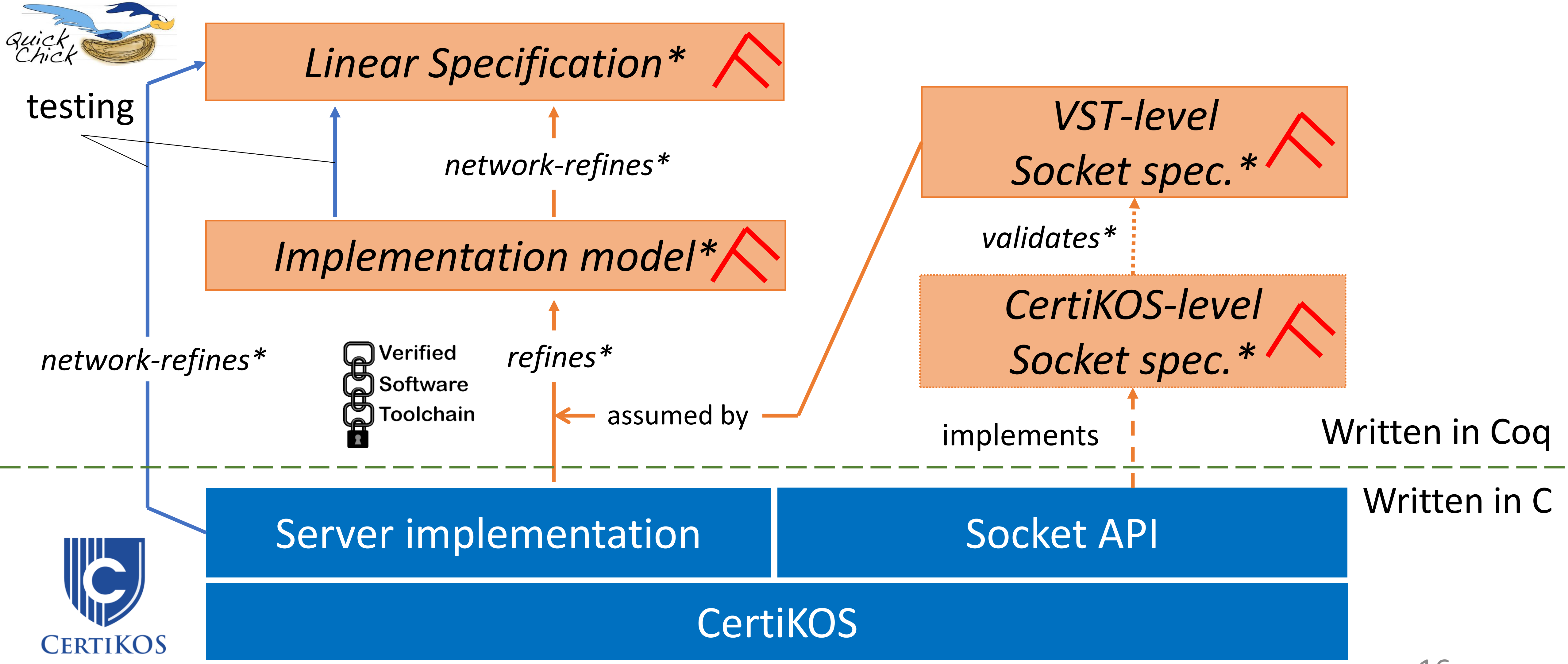
```
CoFixpoint
  loop (open_conns : list conns)
       (last_msg : bytes) : itree serverE unit
  :=
    c <- choose open_conns ;;
    new_msg <- recv_msg c ;;
    send_msg c last_msg ;;
    loop open_conns new_msg.
```

Simplified version (see paper)

Interaction trees

*: concepts defined in the paper

Overview: proof architecture



Refinement: from C to ITrees

Hoare triple: `{ pre1 * … * preN } C_program { post1 * … * postN }`

*Interactions **allowed** by the environment* — *Assertions on C memory* — *Separating conjunction*

```
{ ITree(impl_model) * … } C_program { … }
```

Example of a networked C program with its implementation model:

```
{ ITree(msg <- Recv c ;;
        Send c msg ;;
        t) * … }
```

Implementation model (itree)

```
  recv(c, buf, len);
  send(c, buf, len);
```

C implementation

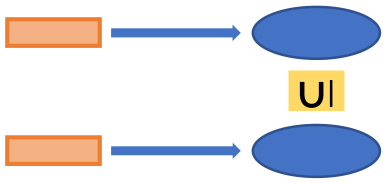
```
{ ITree(t) * … }
```

Simplified triples (see paper)

The Swap server correctness theorem

```
{ ITree(impl_model) } C_prog { … }

Theorem correct_server :
  exists impl_model,
          refines C_prog impl_model /\
    network_refines impl_model linear_spec.
```



Summary and next steps

Complete connection

- Verifying a networked C program using VST, which can run in CertiKOS
- The specification describes a client can observe *over the network*
- The specification is testable, using QuickChick *and Interaction trees*

Scale up:
Swap server ->
HTTP Server

Add more interfaces:
filesystem, encryption…

Improve proof
and testing
techniques

New library

https://github.com/DeepSpec/InteractionTrees