Towards proving security in the presence of large untrusted components

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Australian Research Council

NICTA Members

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Computers and Trust

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- Advances in formal methods techniques give us hope
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How can we provide *any* formal assurance to real-world systems of such size?

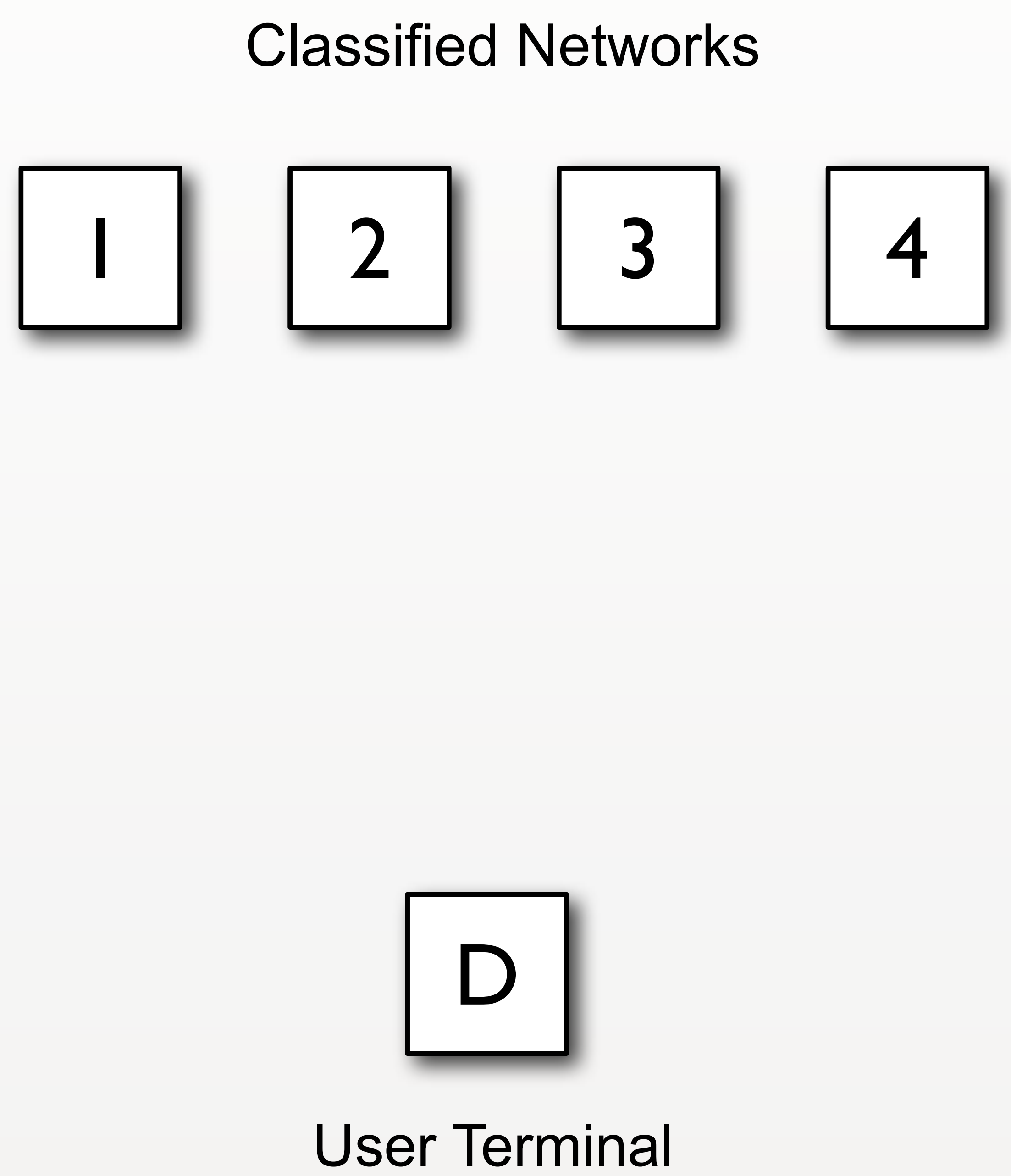
Our Vision

- Provide full system guarantees for *targeted* properties

- Isolate the software parts that are not critical to the target property
  - And then prove that nothing more needs to be said about it

- Formally prove that the remaining parts satisfy the target property

Case Study: Secure Access Controller



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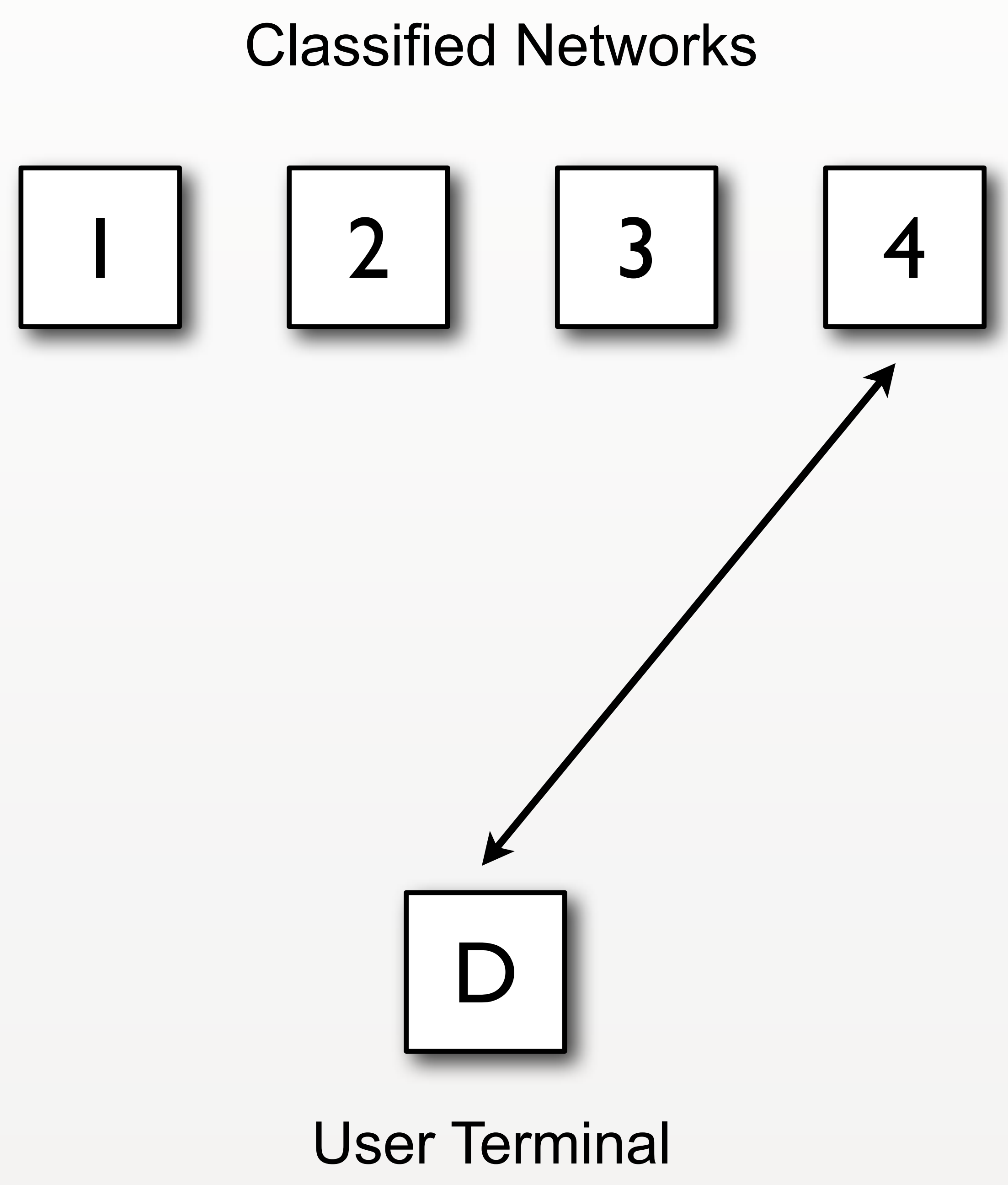

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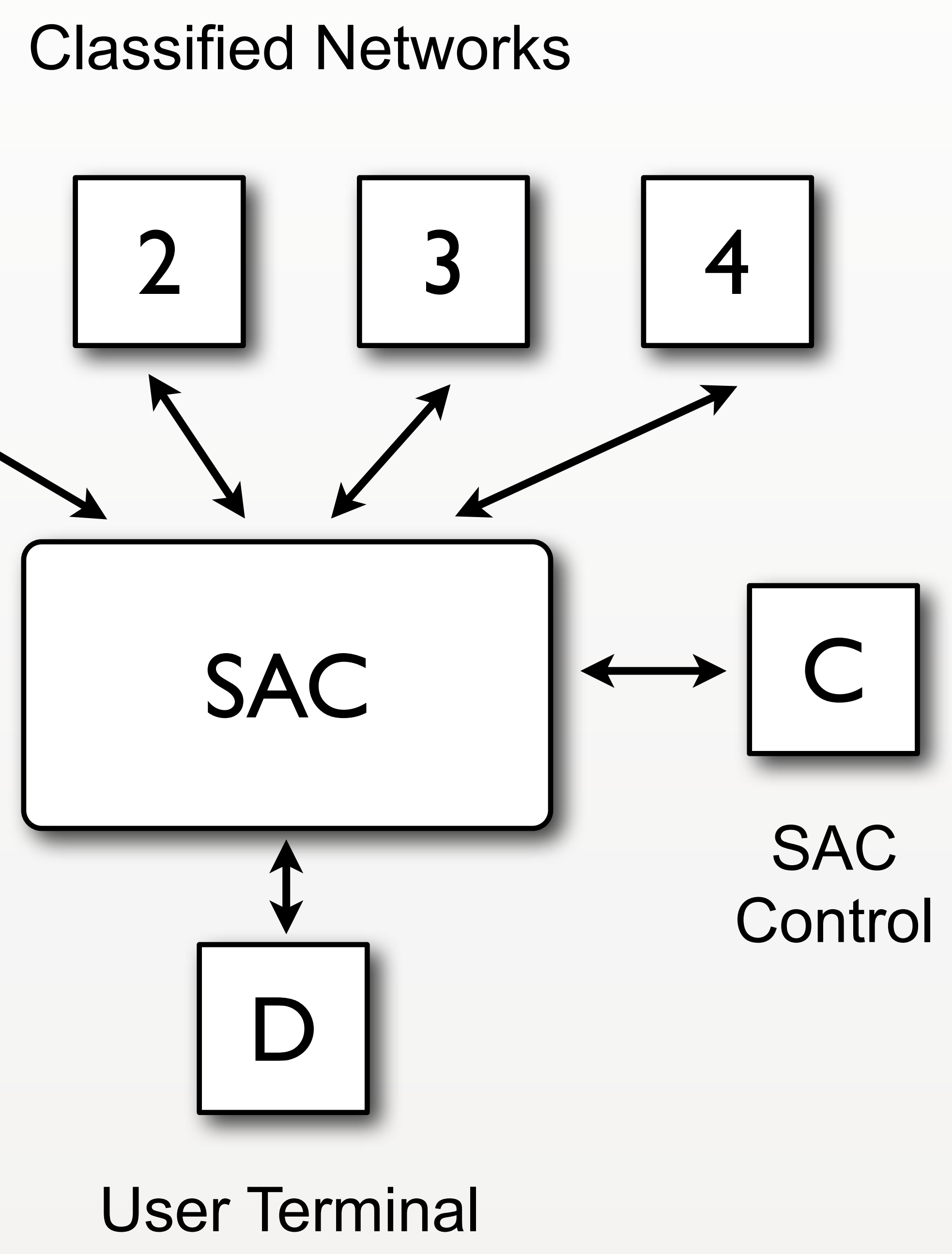

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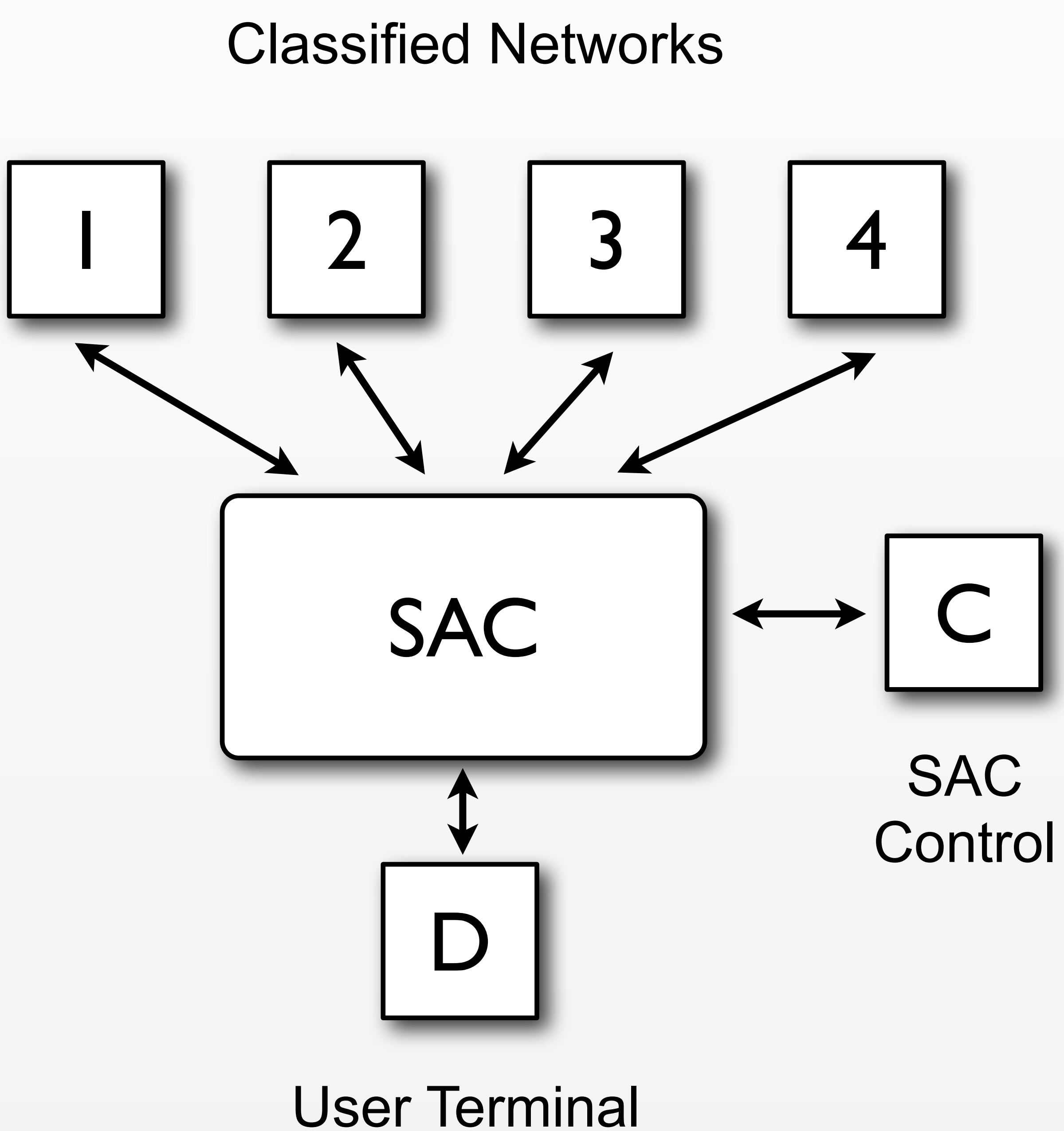

- Data from one classified network must not reach another
- Assumptions:
  - User terminal will not leak data
  - Only verify overt communication channels
  - All networks are otherwise malicious

Case Study: Secure Access Controller

SAC

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Gigabit
Network Card
Drivers

10,000 LoC

SAC

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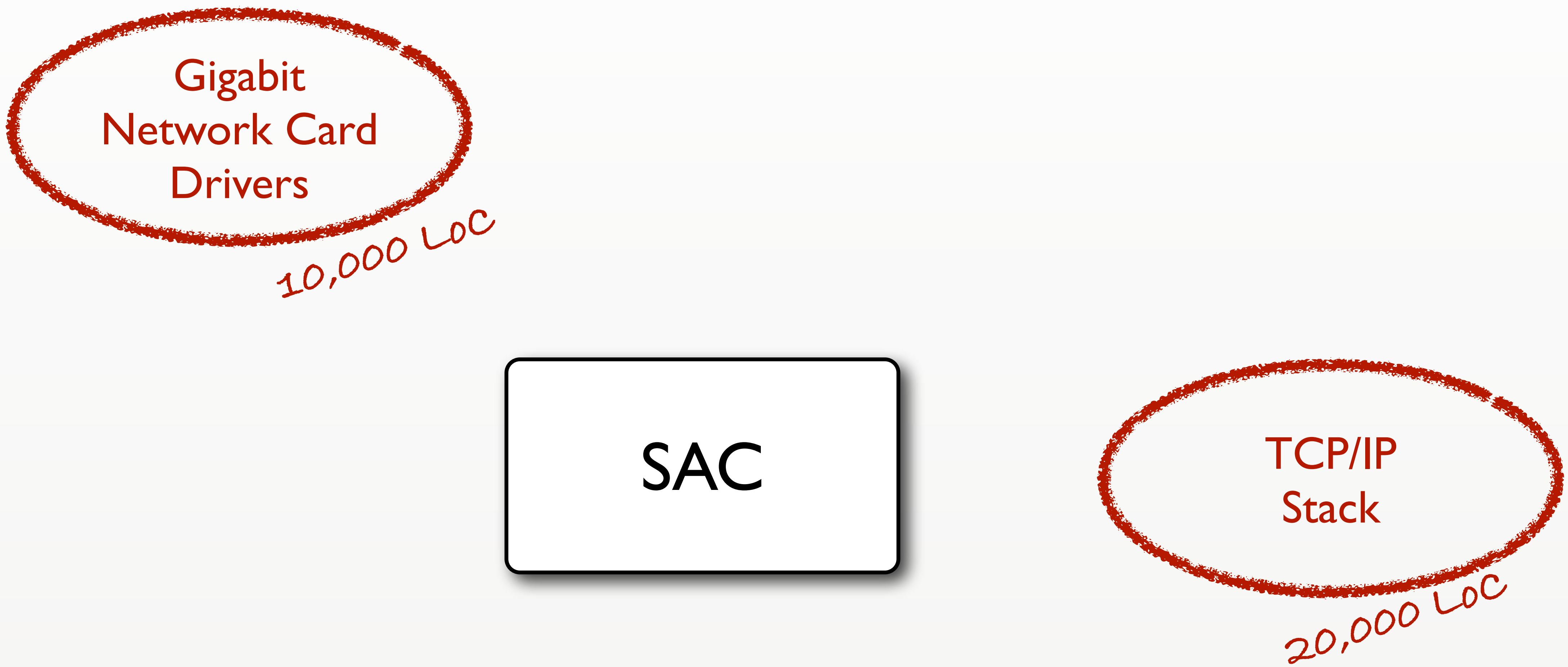

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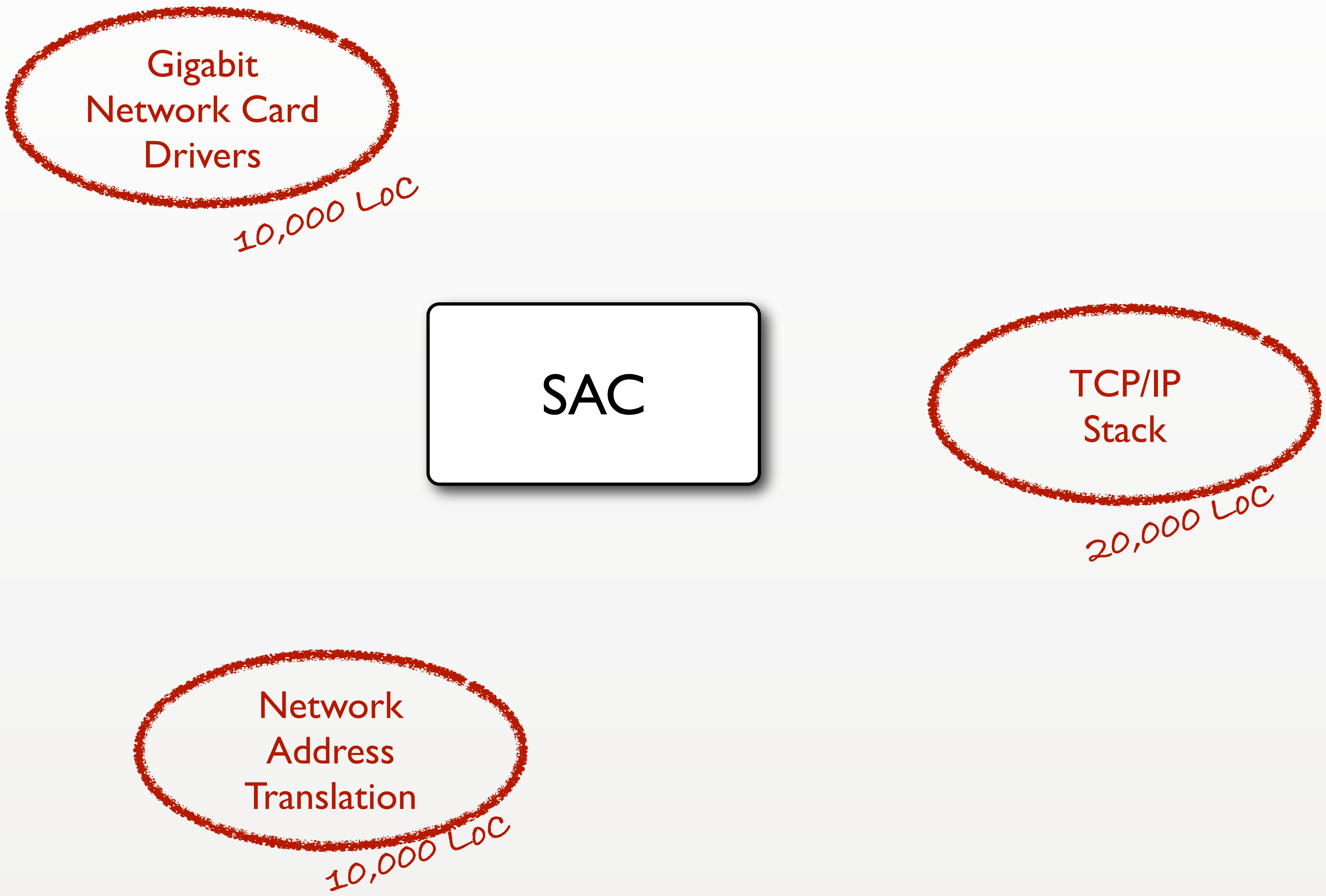

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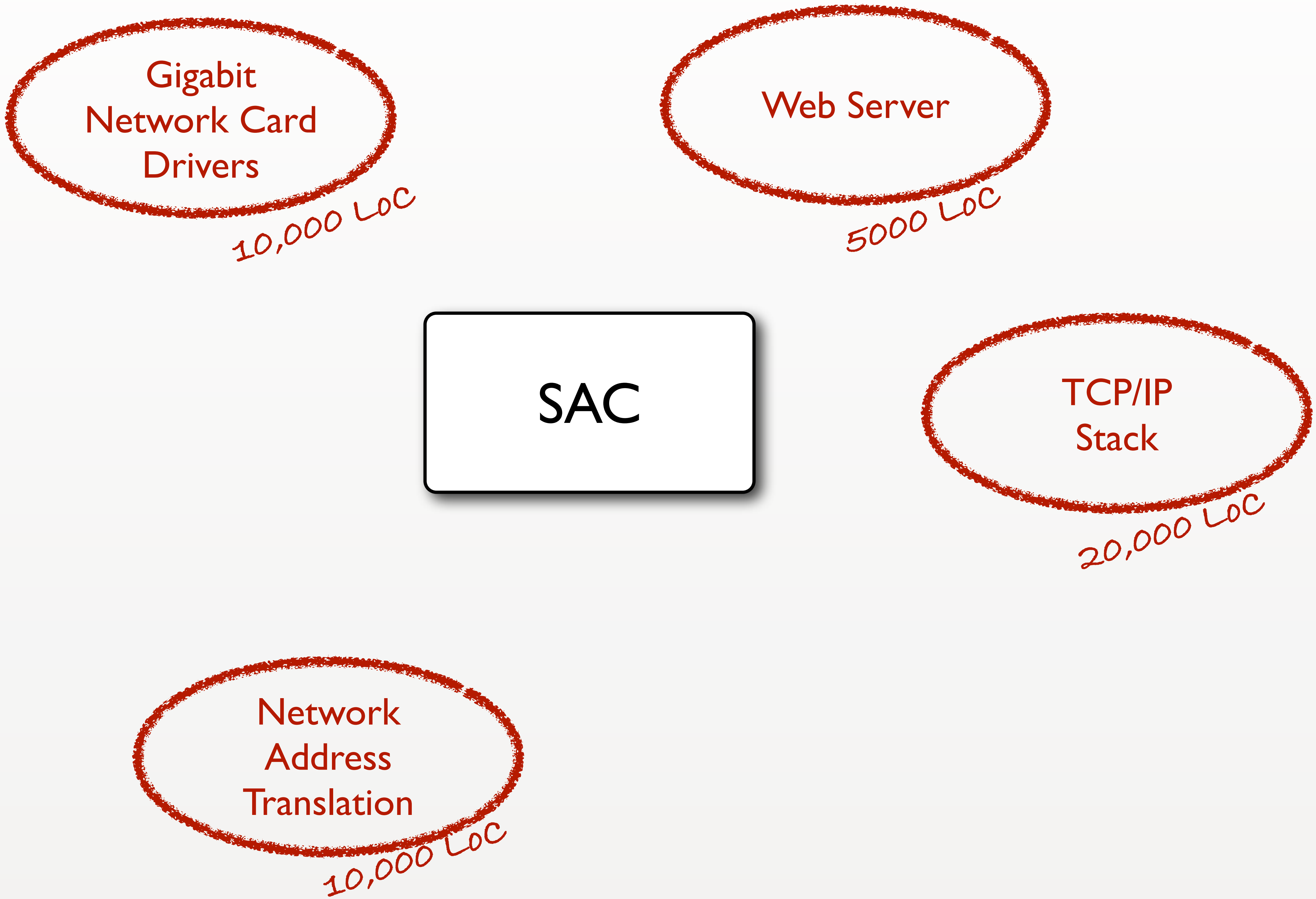

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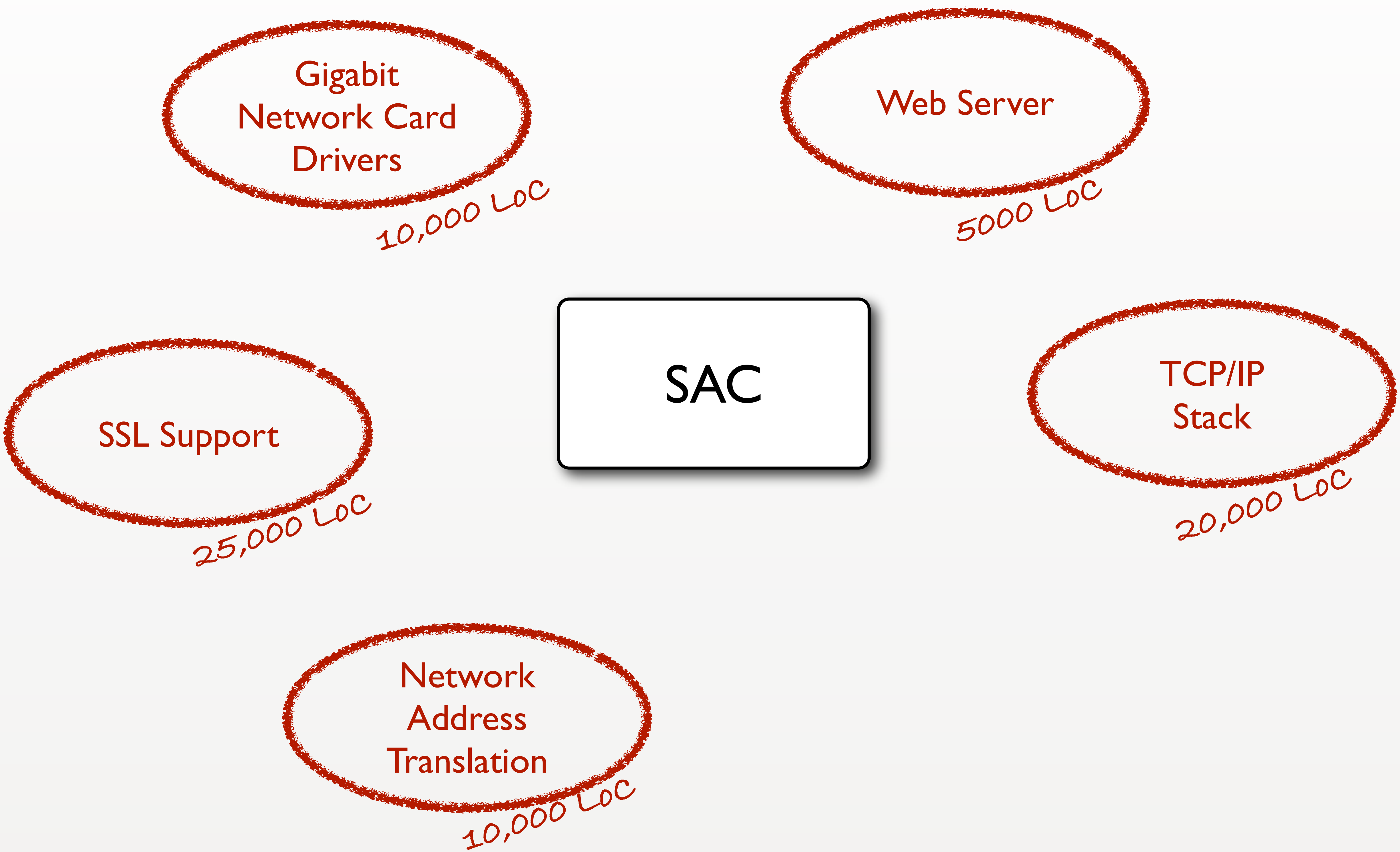

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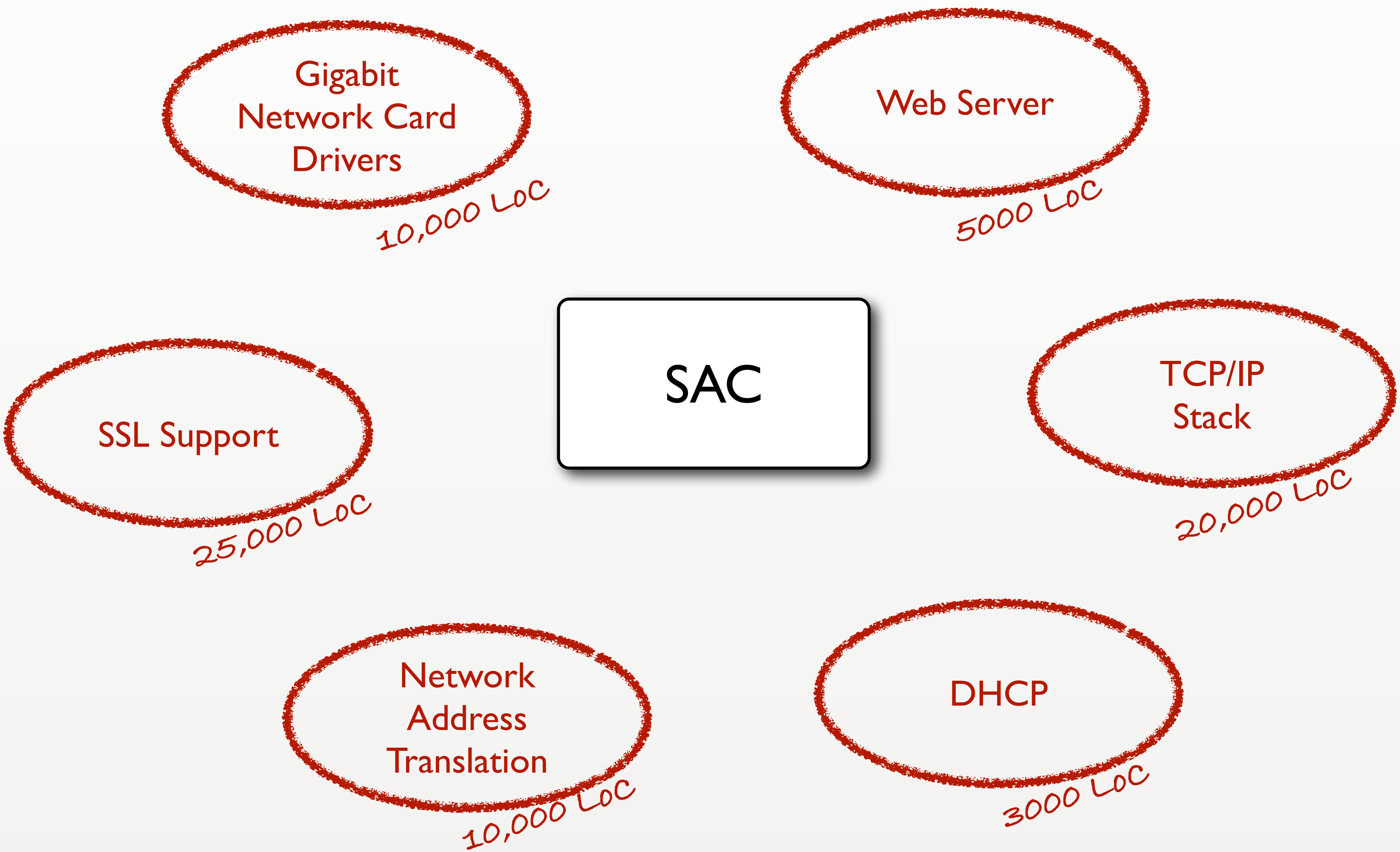

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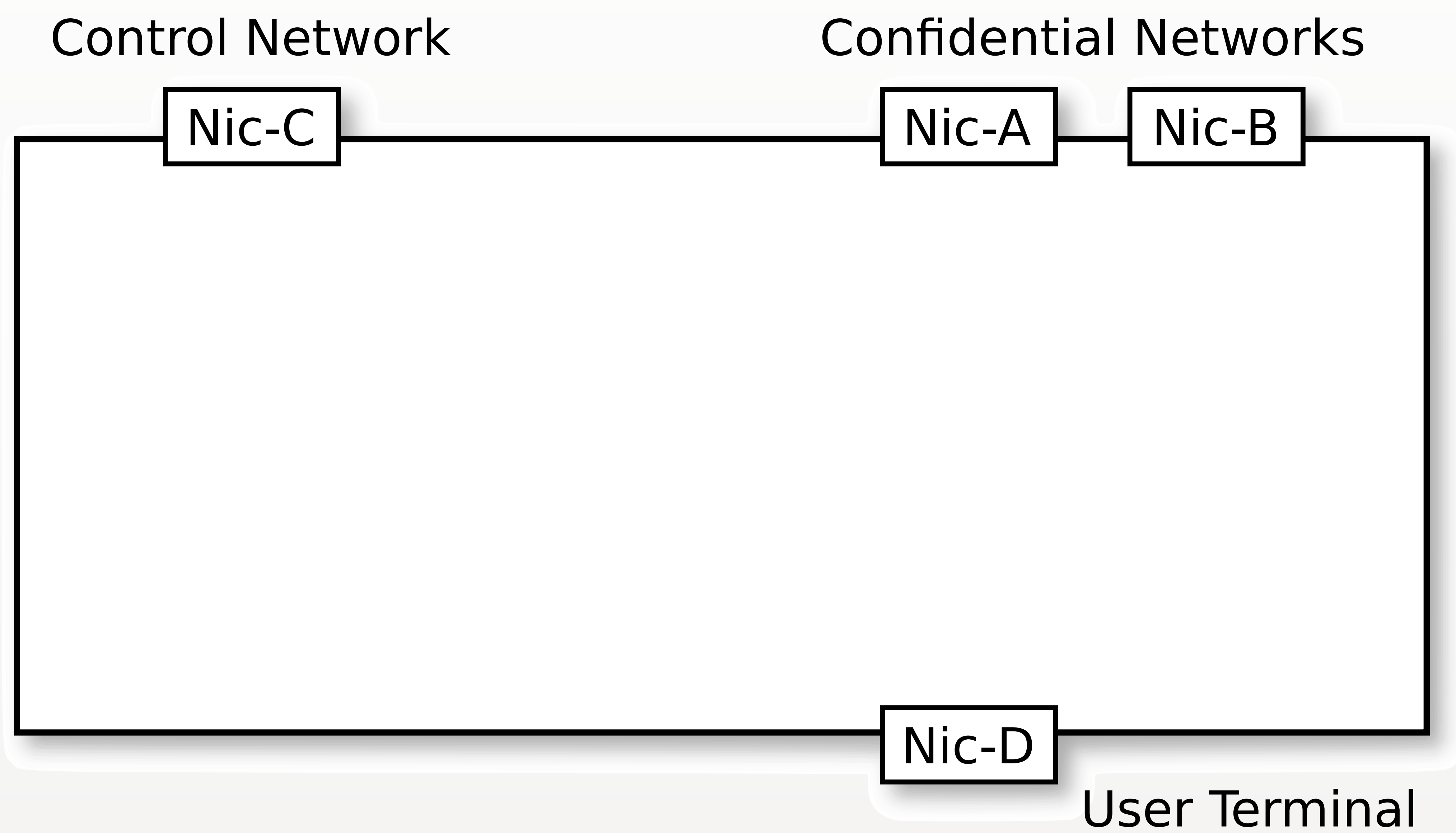

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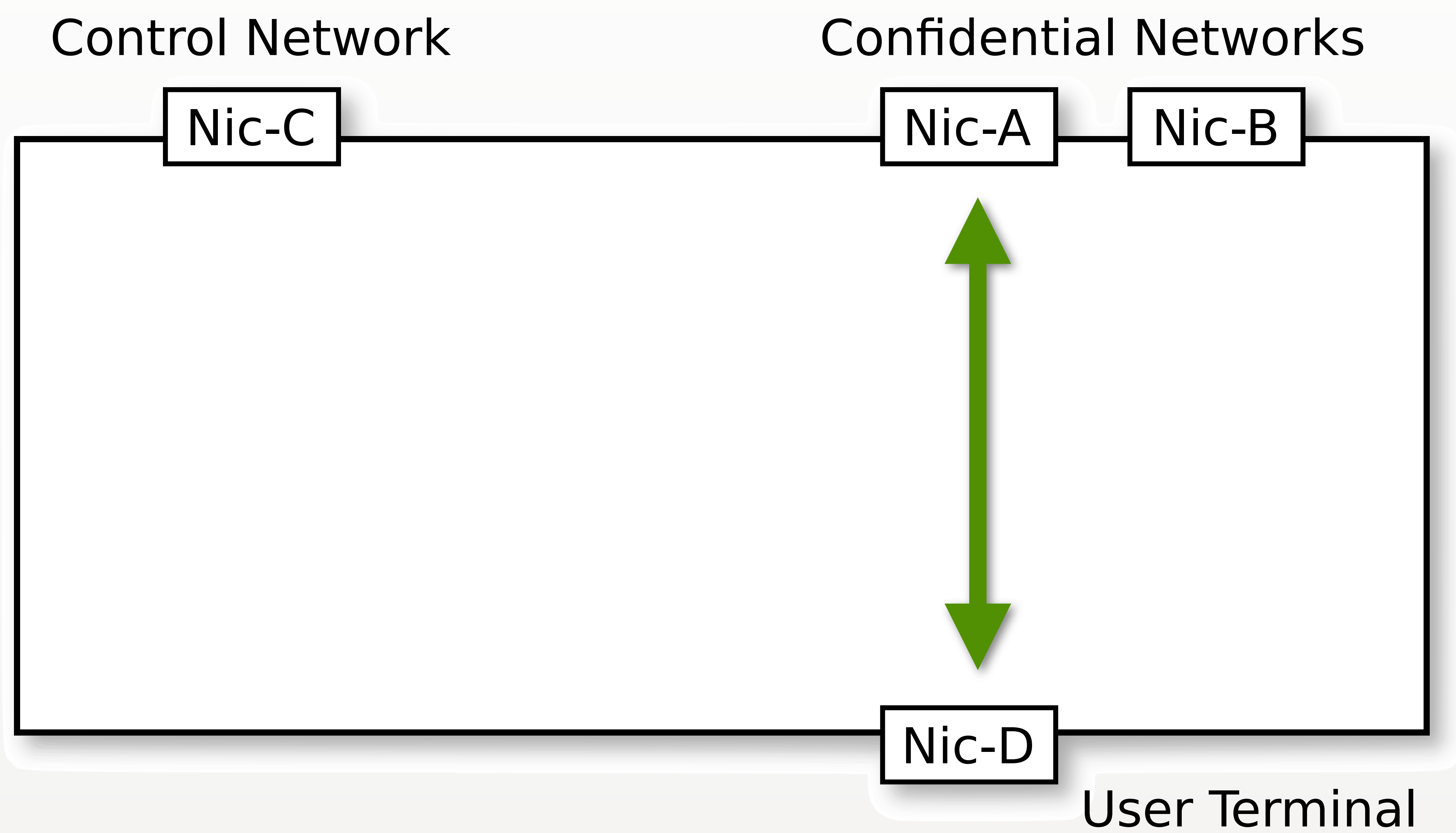

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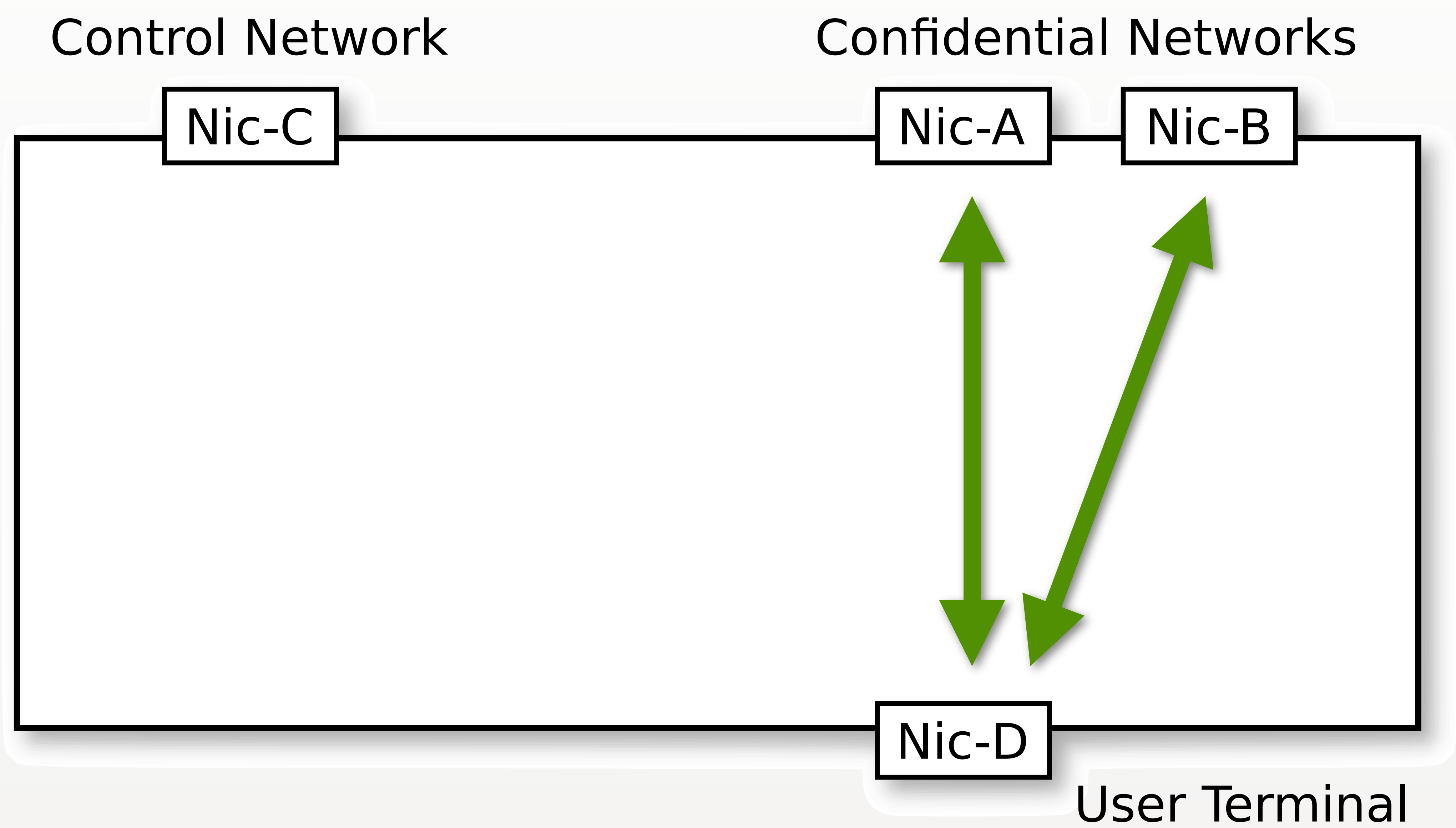

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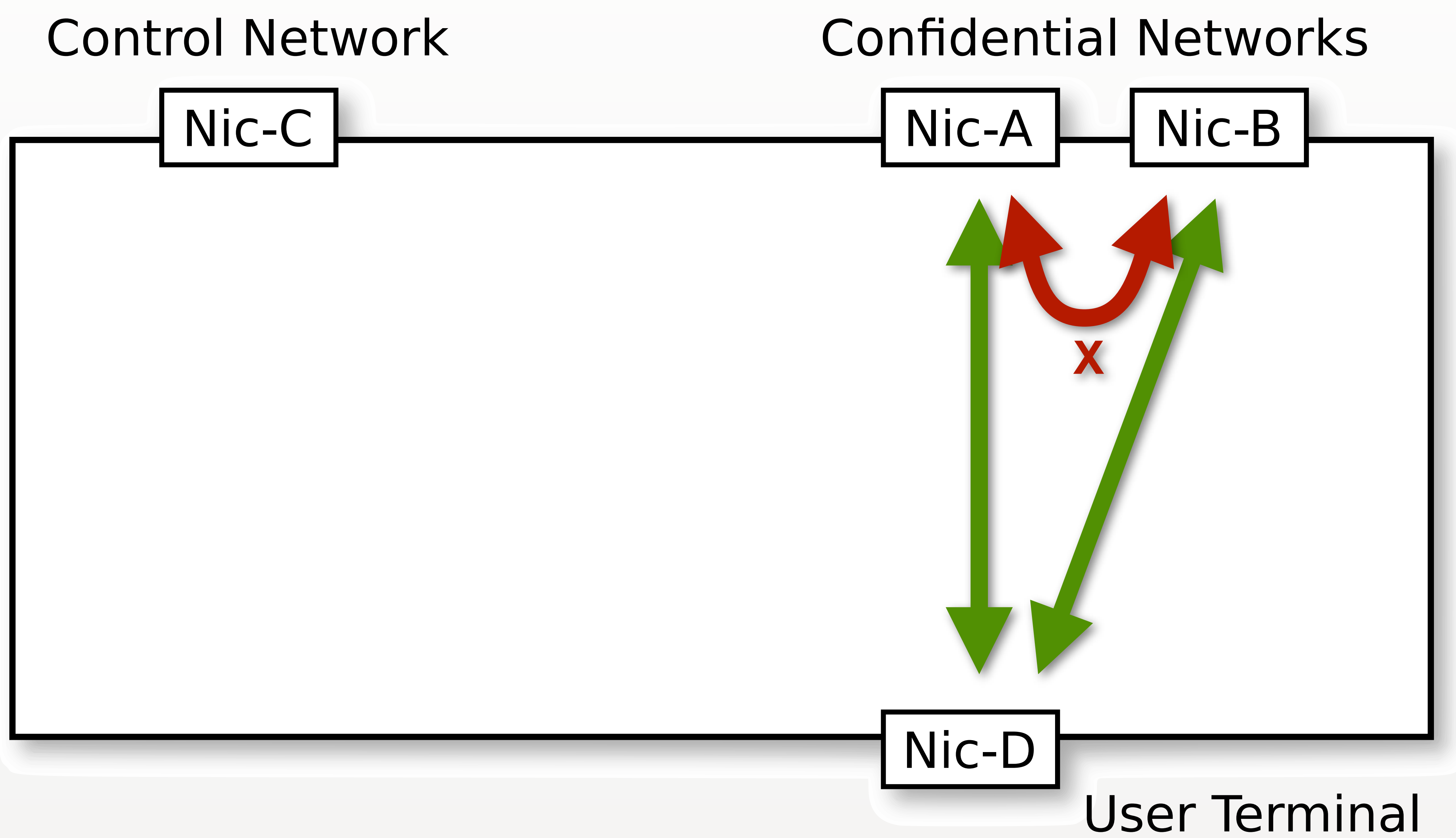


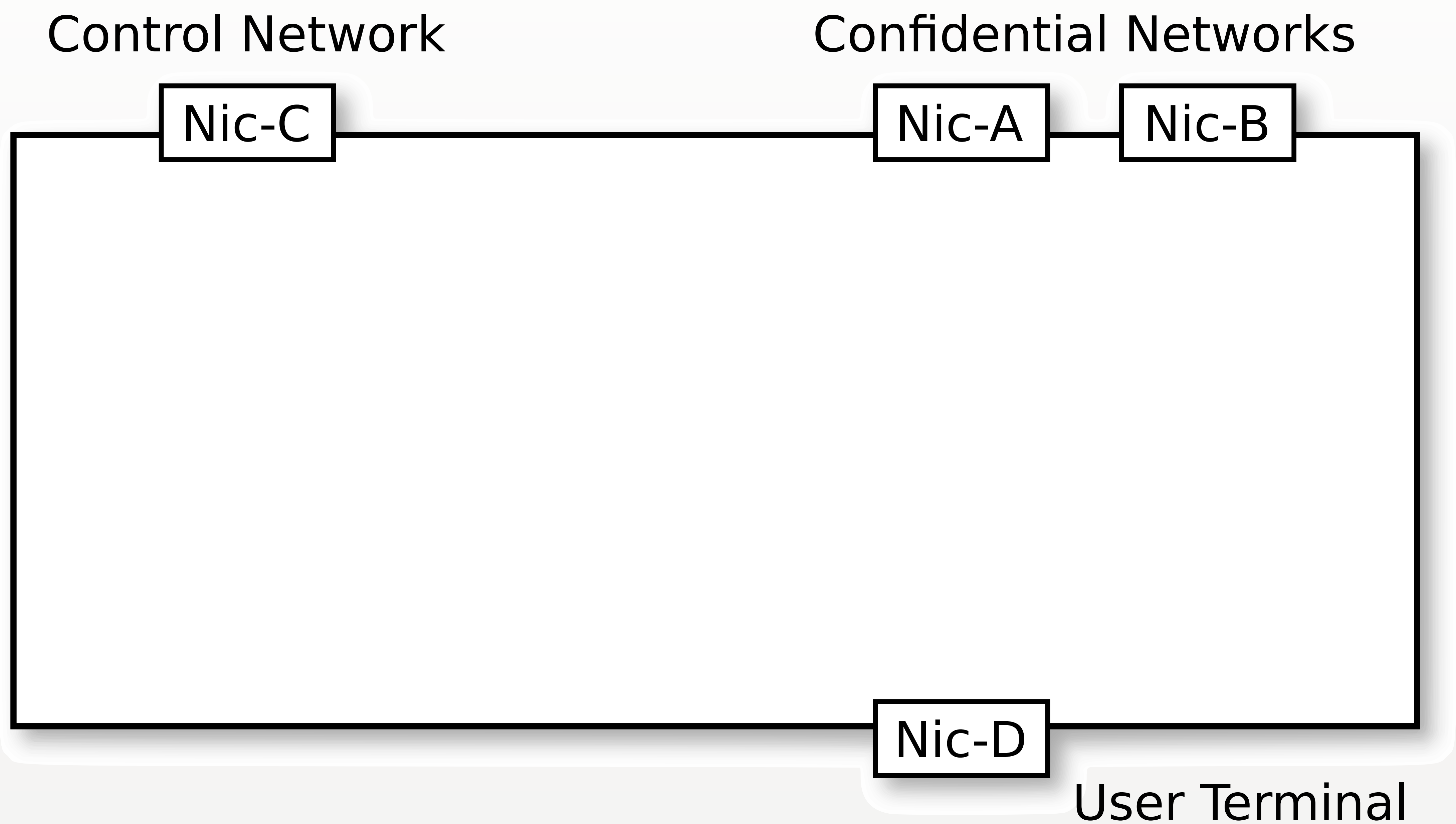
Case Study: Secure Access Controller

- Verification of all code in the system is infeasible
- Instead, split up code into components
  - Trusted / untrusted components
  - Only give components access to resources they need
  - Principle of least privilege
- To do this, we need some mechanism to enforce this split

seL4 Microkernel

- Small operating system kernel
  - Threads
  - Address Spaces
  - Communication primitives
- Capability based
  - All system resources require a cap to be accessed
  - Provides access control, allowing threads to be isolated by using an appropriate cap distribution
- Proven functionally correct
  - seL4's C code shown to correctly implement its specification
    - Assumes correctness of hardware, compiler, initialisation code, assembly paths

SAC Security Architecture



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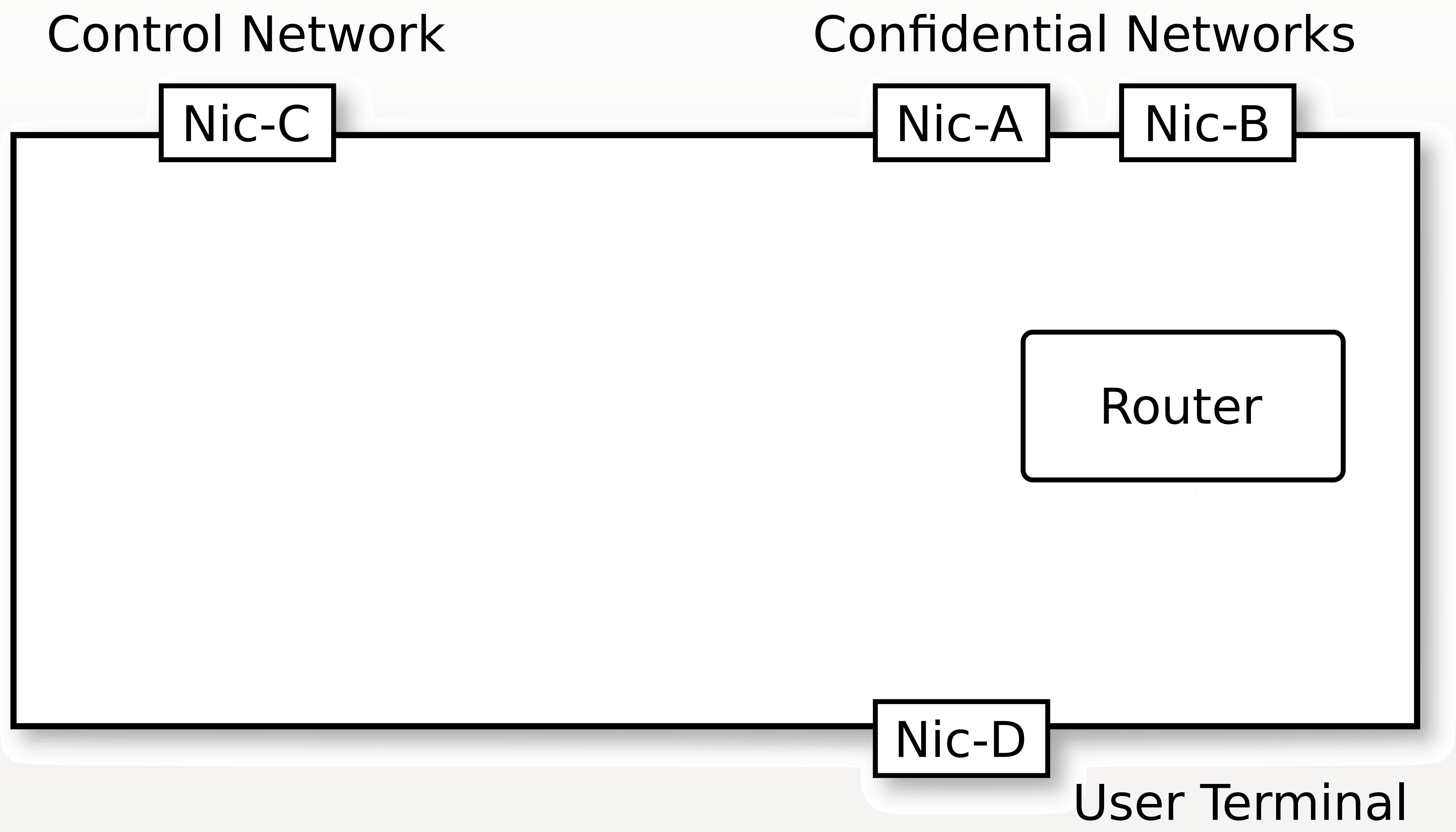

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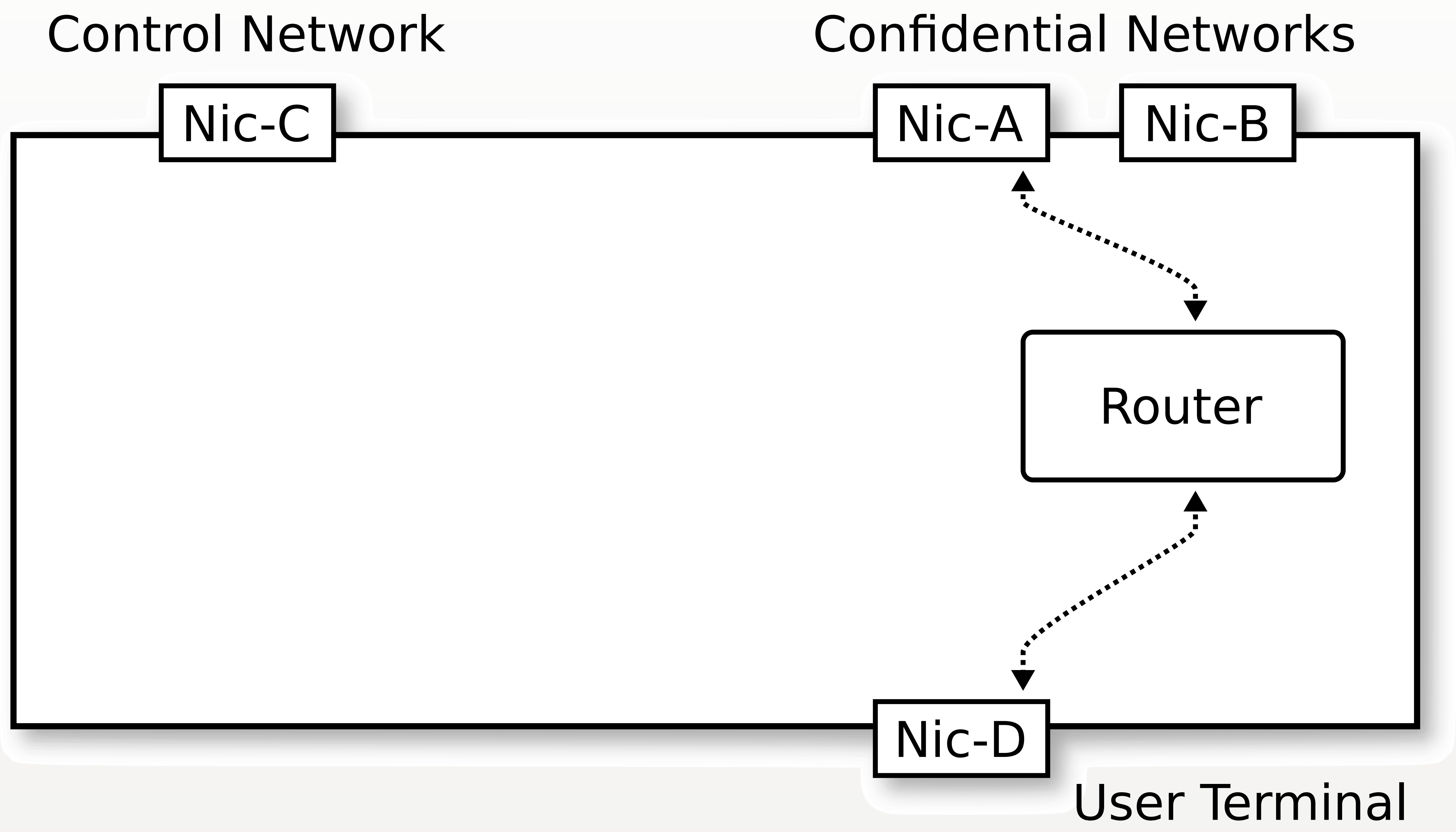

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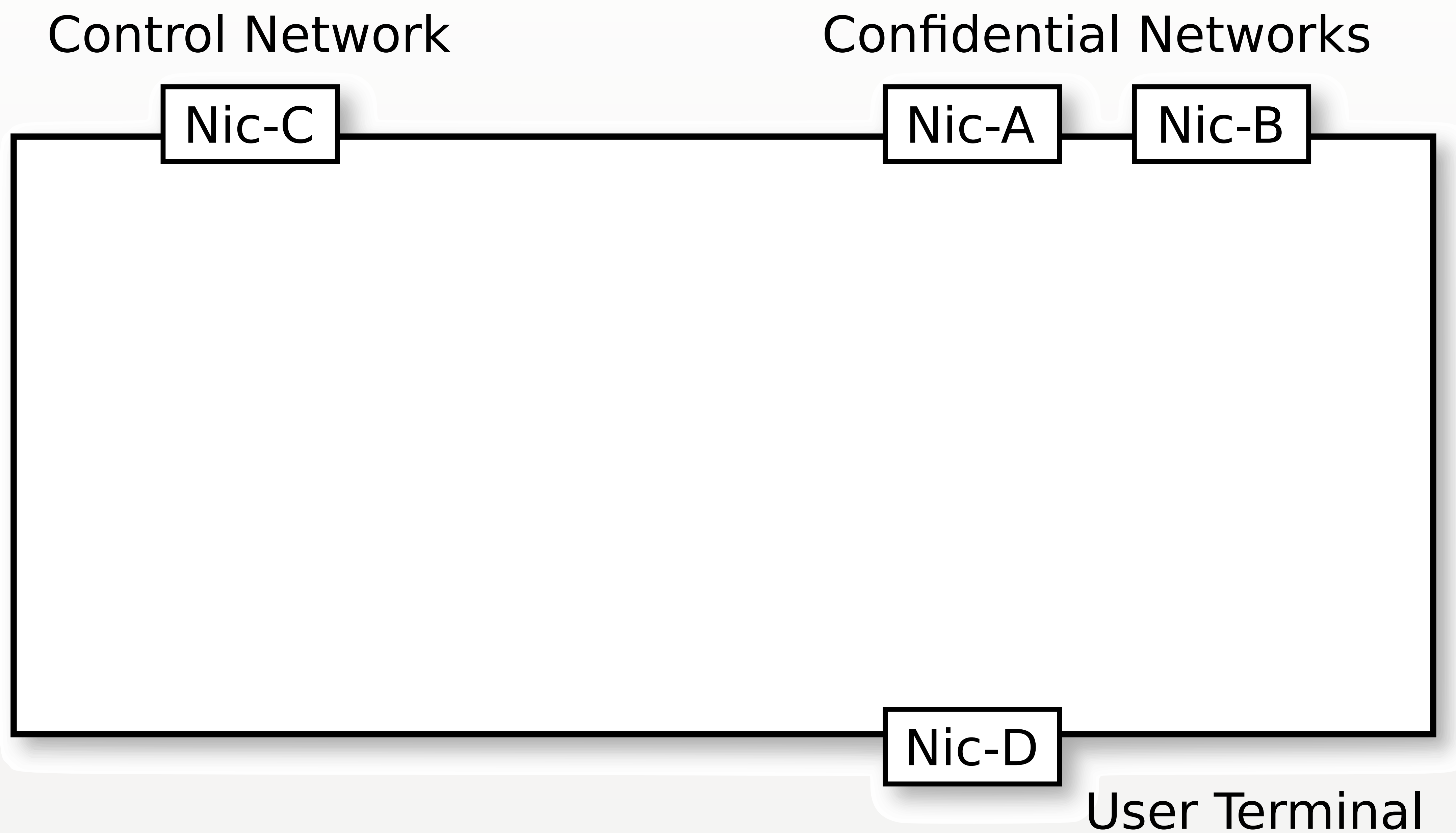

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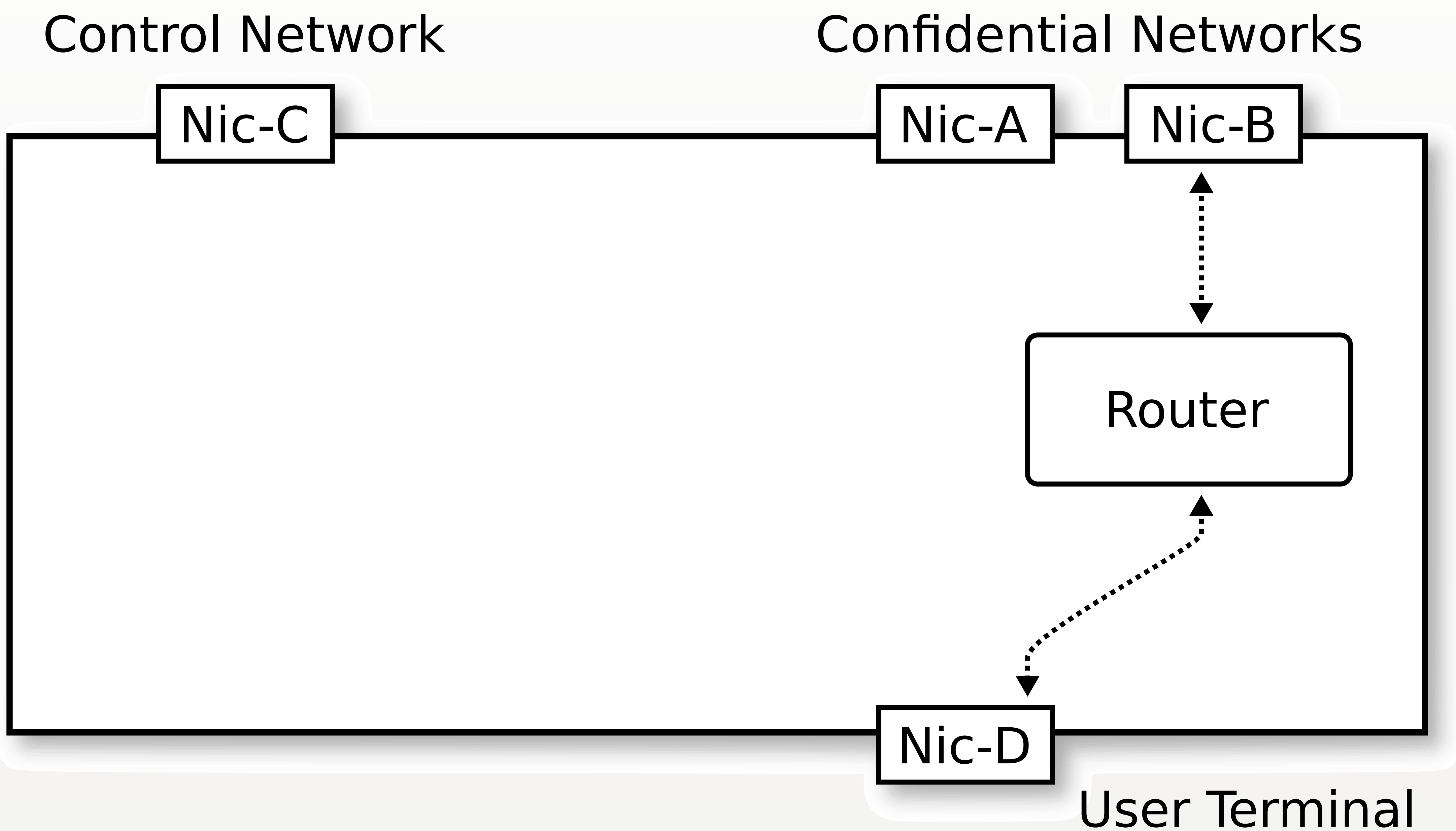

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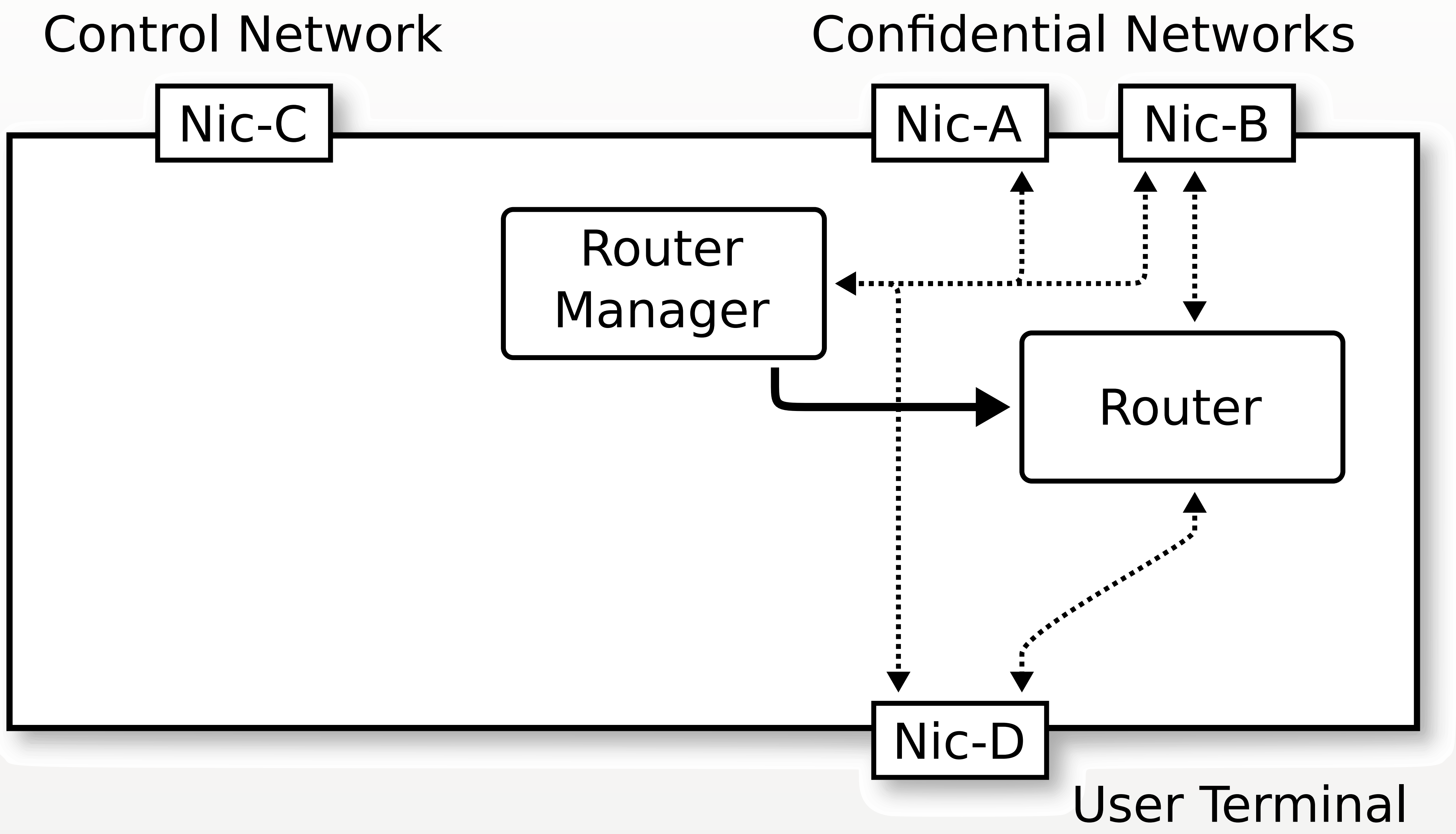

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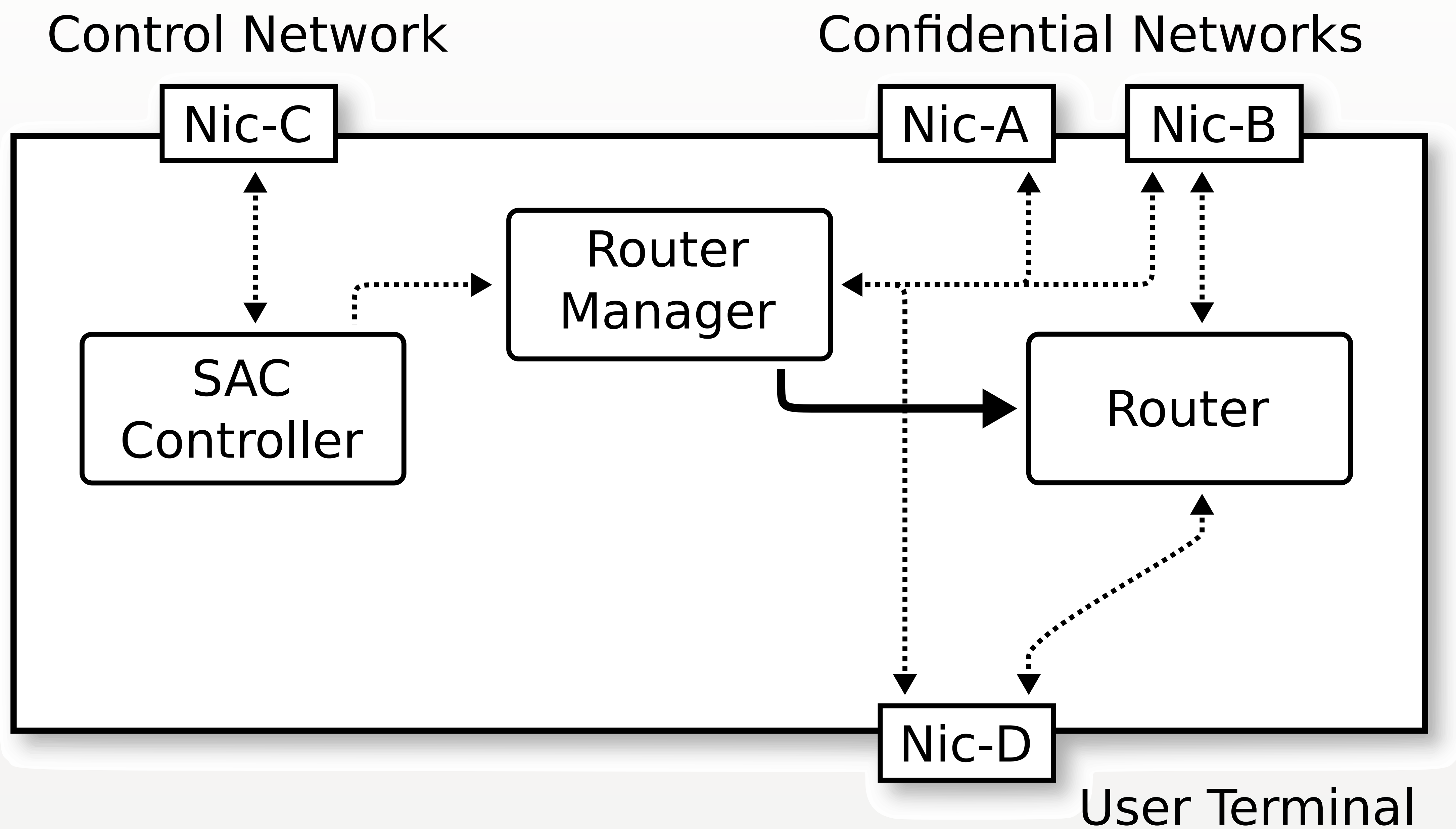

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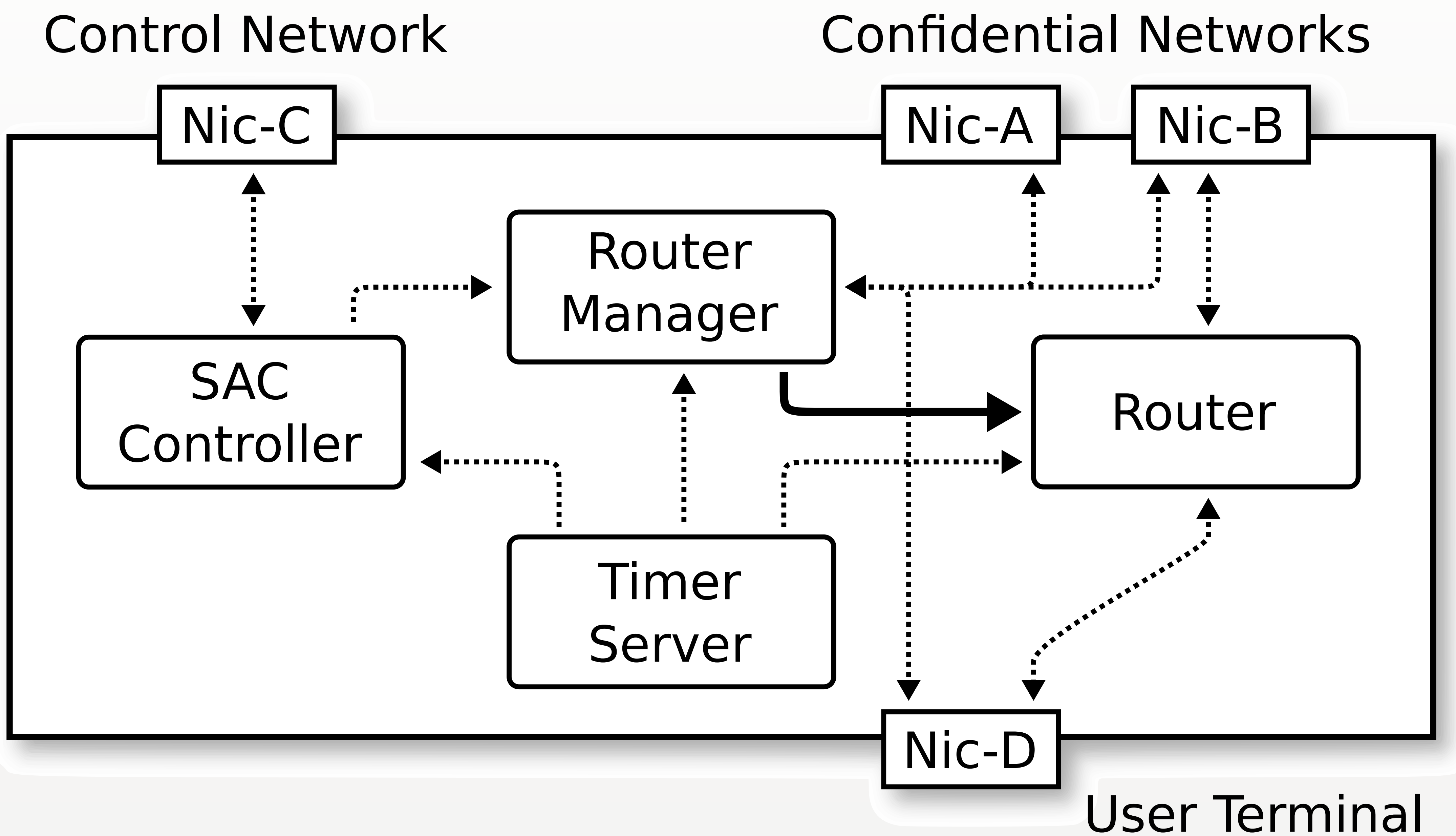

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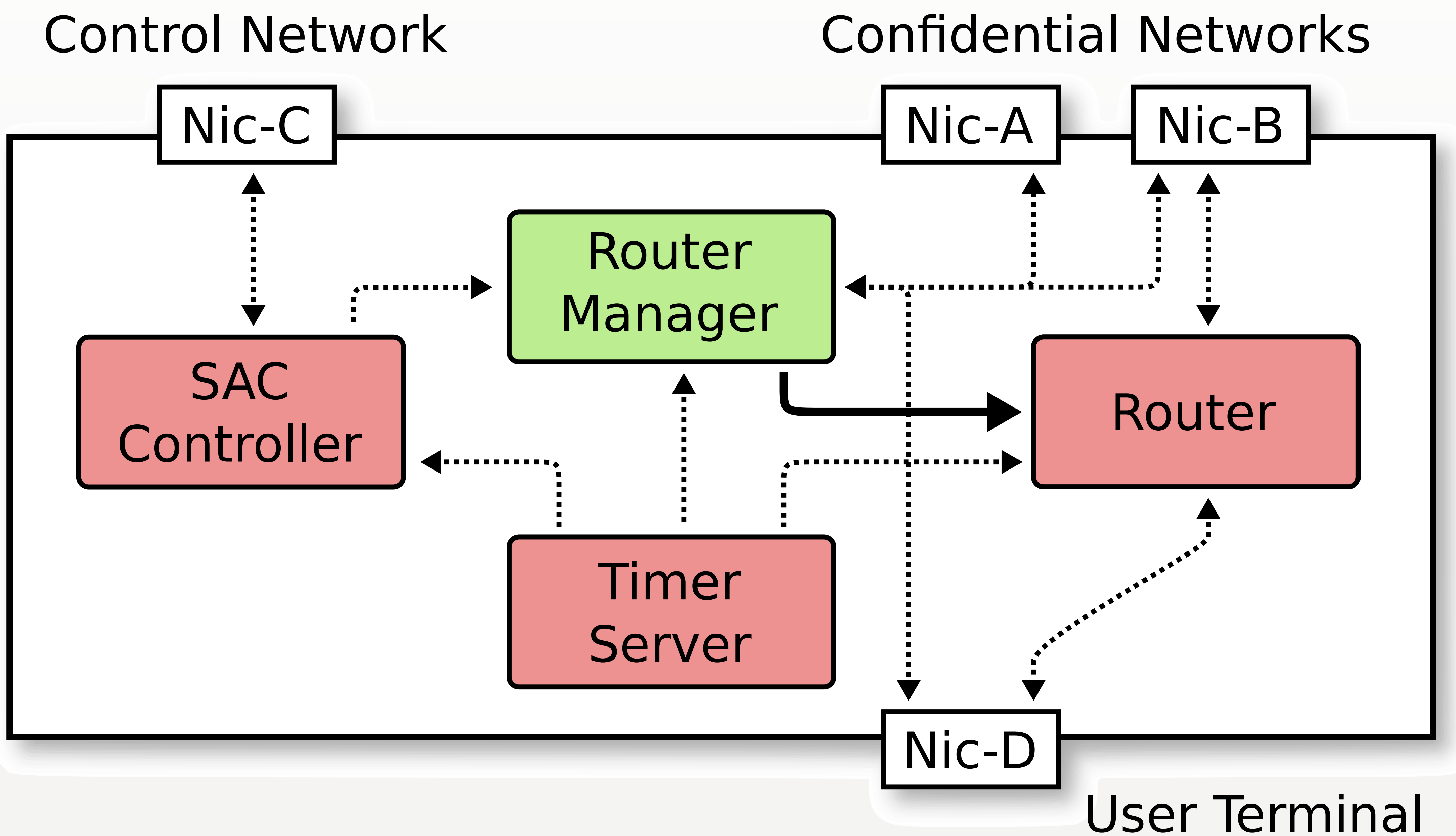
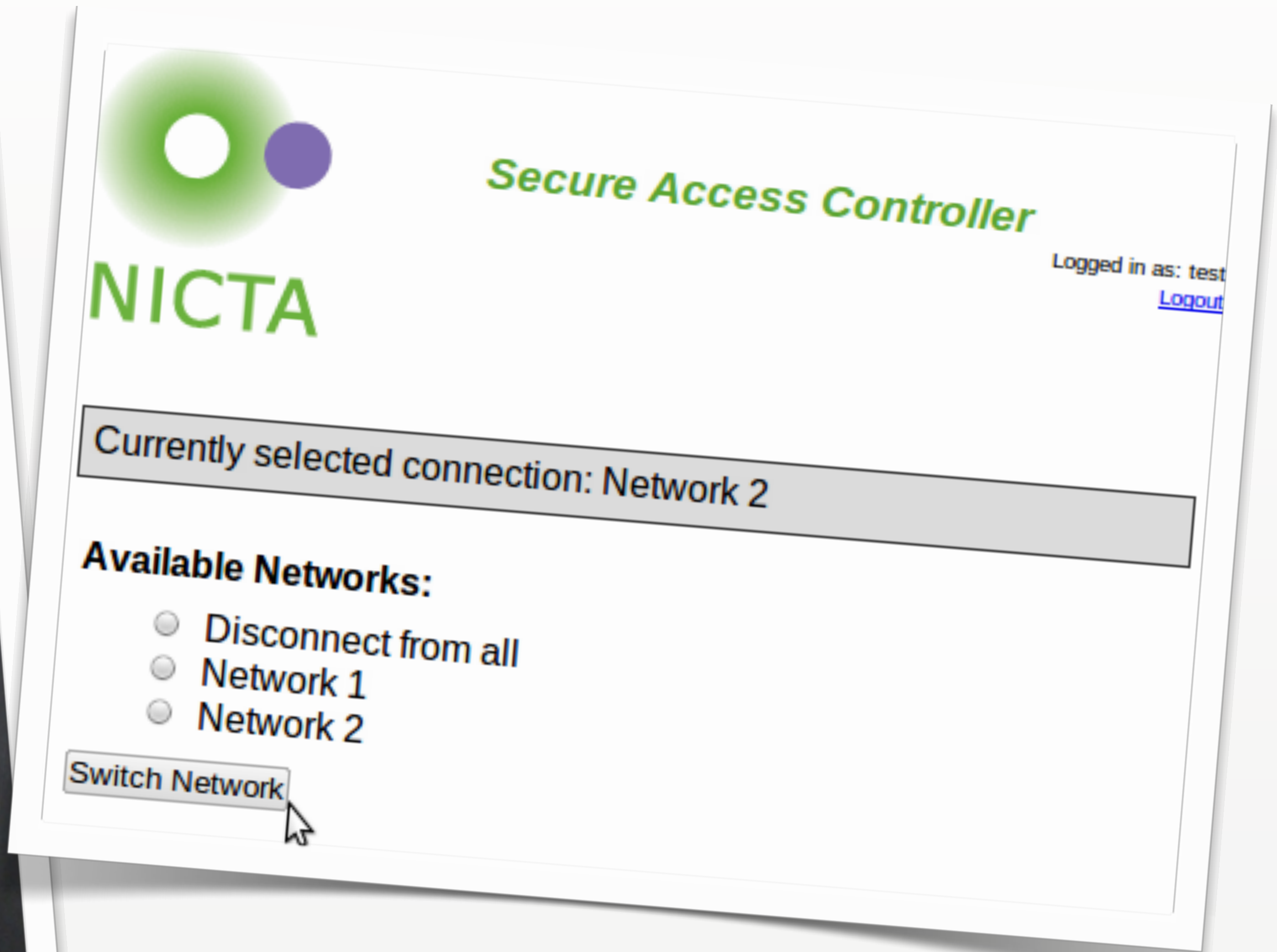
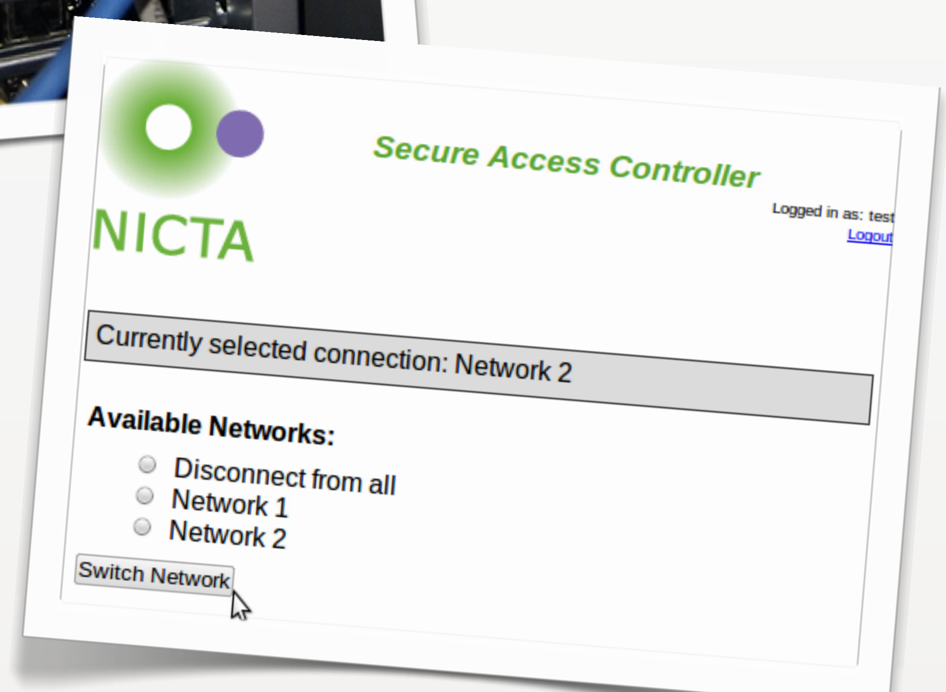


SAC Prototype



SAC Prototype

- Router
  - Virtualised Linux
  - Routing Code / NAT
- SAC Controller
  - Virtualised Linux
  - mini-httpd / OpenSSL
- Timer
  - Hand-written C
- Router Manager
  - Hand-written C
- seL4 Kernel
  - Hand-written C



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- Router
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  - Routing Code / NAT

  } 10,000,000 LoC
- SAC Controller
  - Virtualised Linux
  - mini-httpd / OpenSSL

  } 10,000,000 LoC
- Timer
  - Hand-written C

  } 300 LoC
- Router Manager
  - Hand-written C

  } 1500 LoC
- seL4 Kernel
  - Hand-written C

  } 8300 LoC

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NICTA

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  - Routing Code / NAT

10,000,000 LoC

- SAC Controller
  - Virtualised Linux
  - mini-httpd / OpenSSL

10,000,000 LoC

~20,000,000 lines of code

- Timer
  - Hand-written C

300 LoC

- Router Manager
  - Hand-written C

1500 LoC

- seL4 Kernel
  - Hand-written C

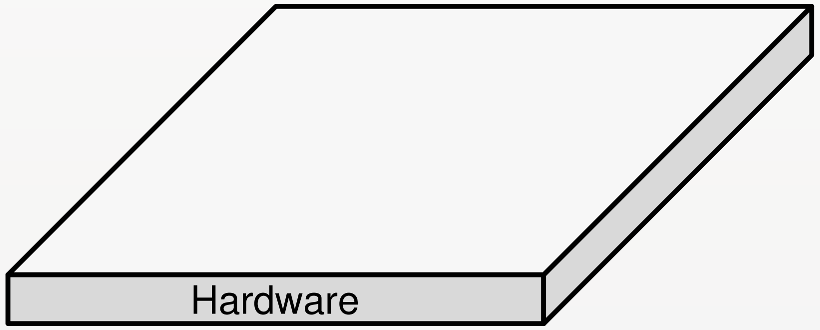
8300 LoC

~10,000 lines of code

Full System Verification

- Merely *reducing* the amount of code isn’t sufficient to provide any security guarantee
- Our goal is to provide a formal guarantee
- How can we achieve this?

Full System Verification



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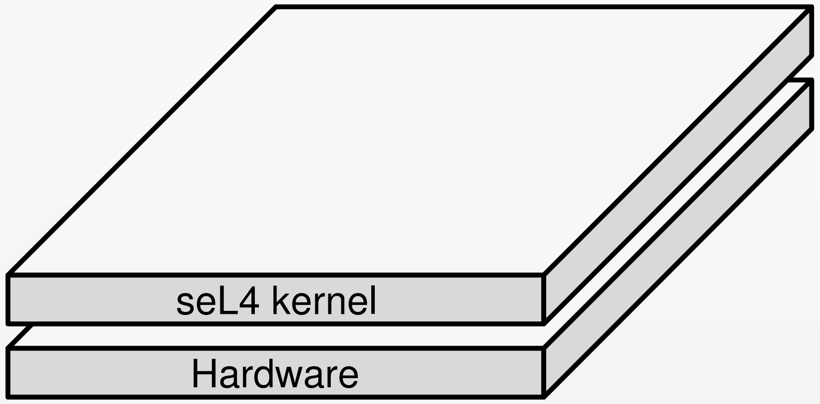

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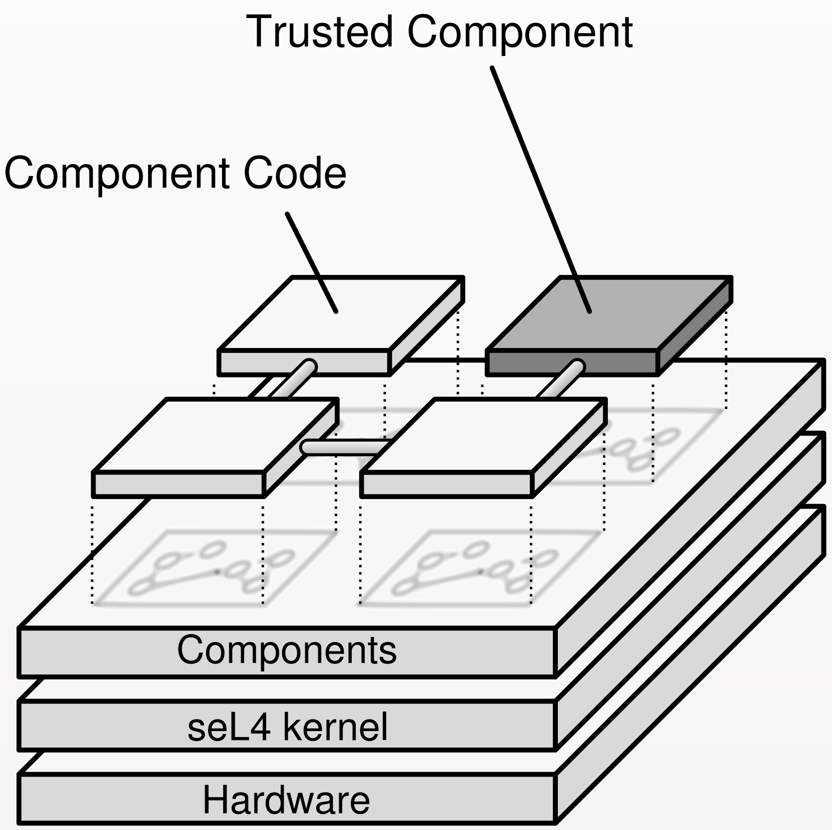

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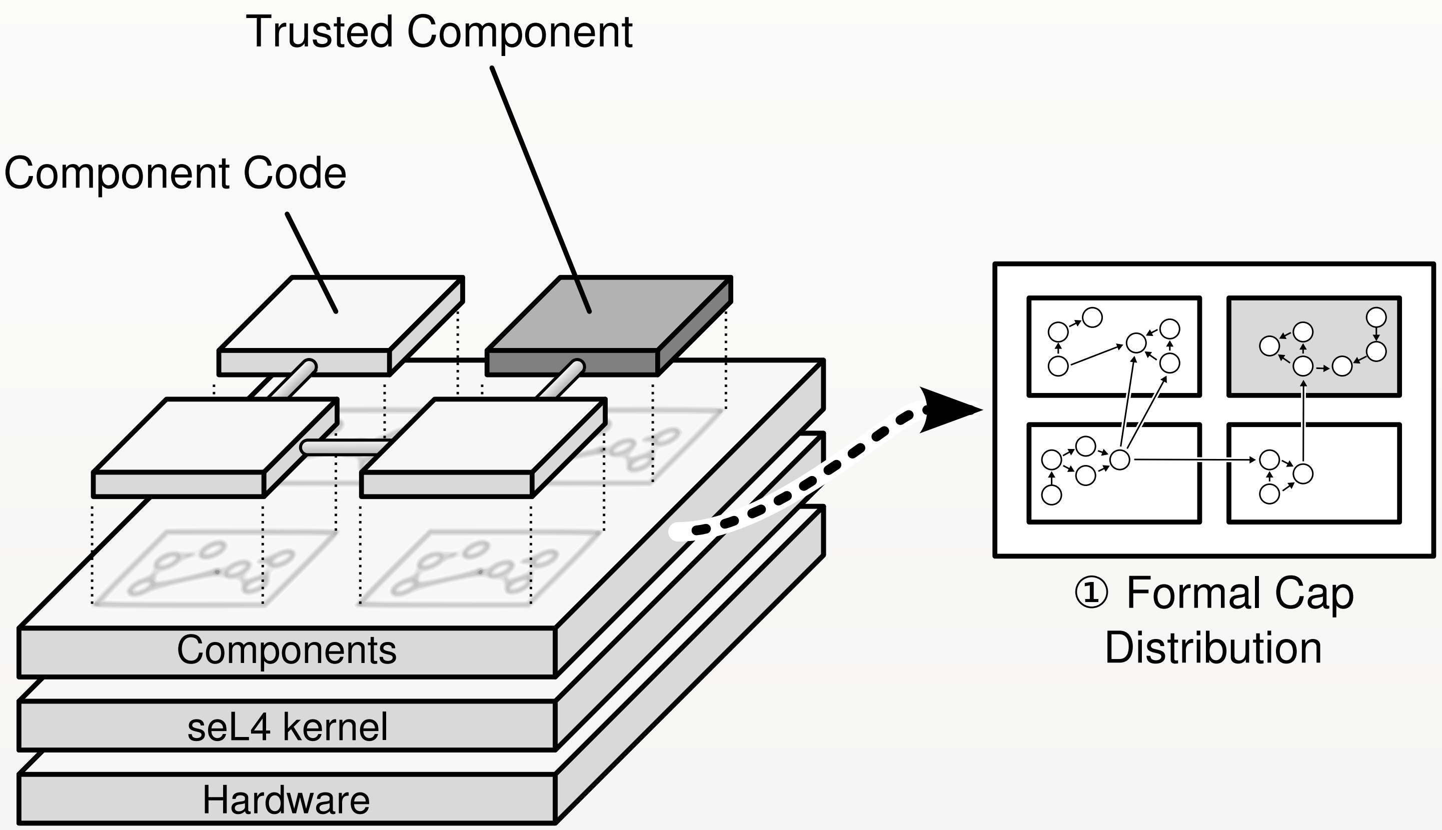

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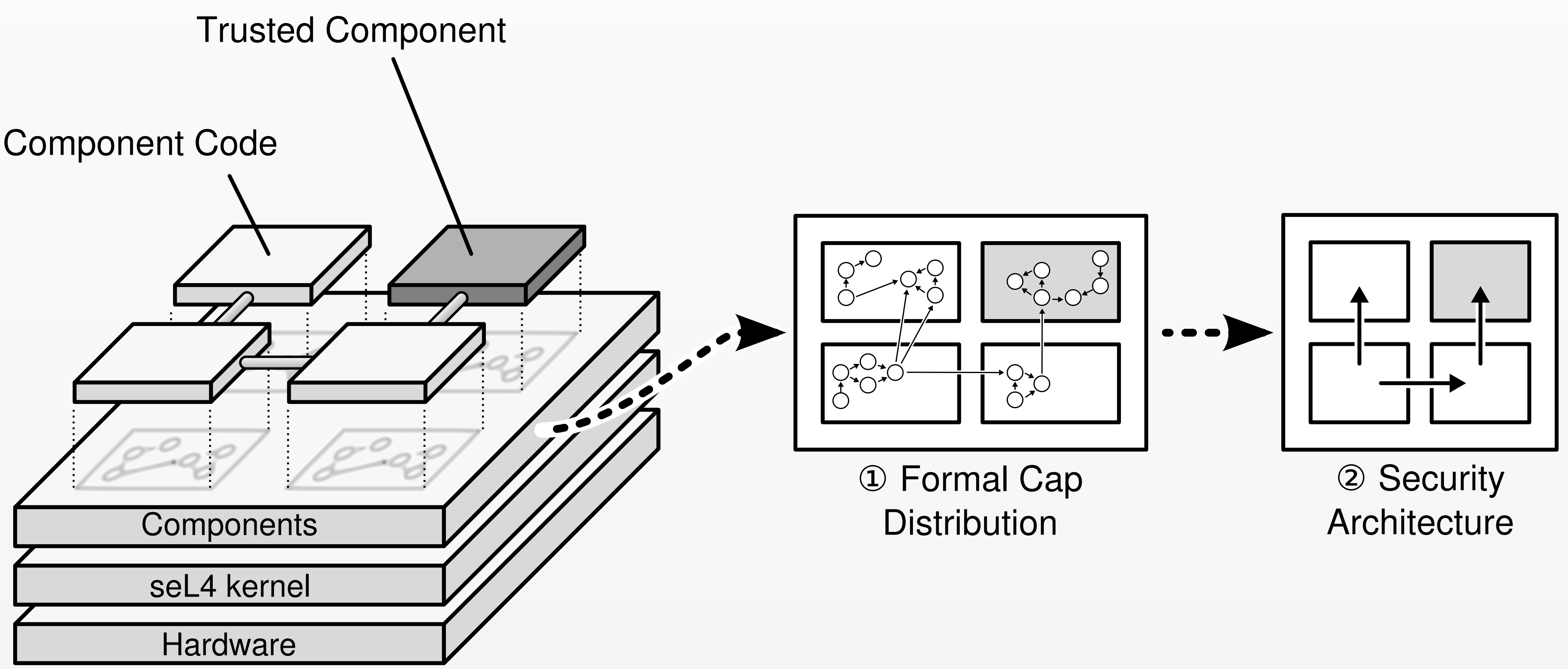

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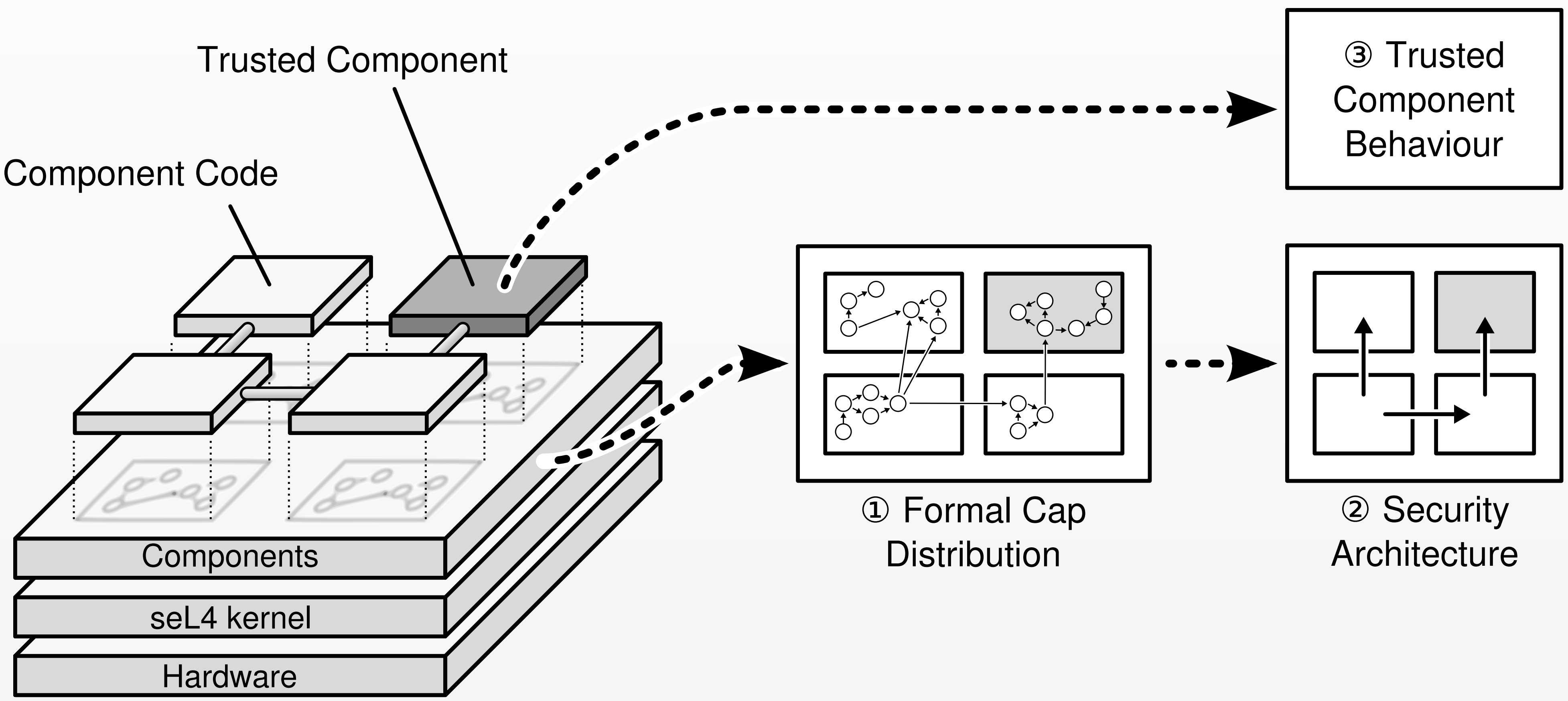

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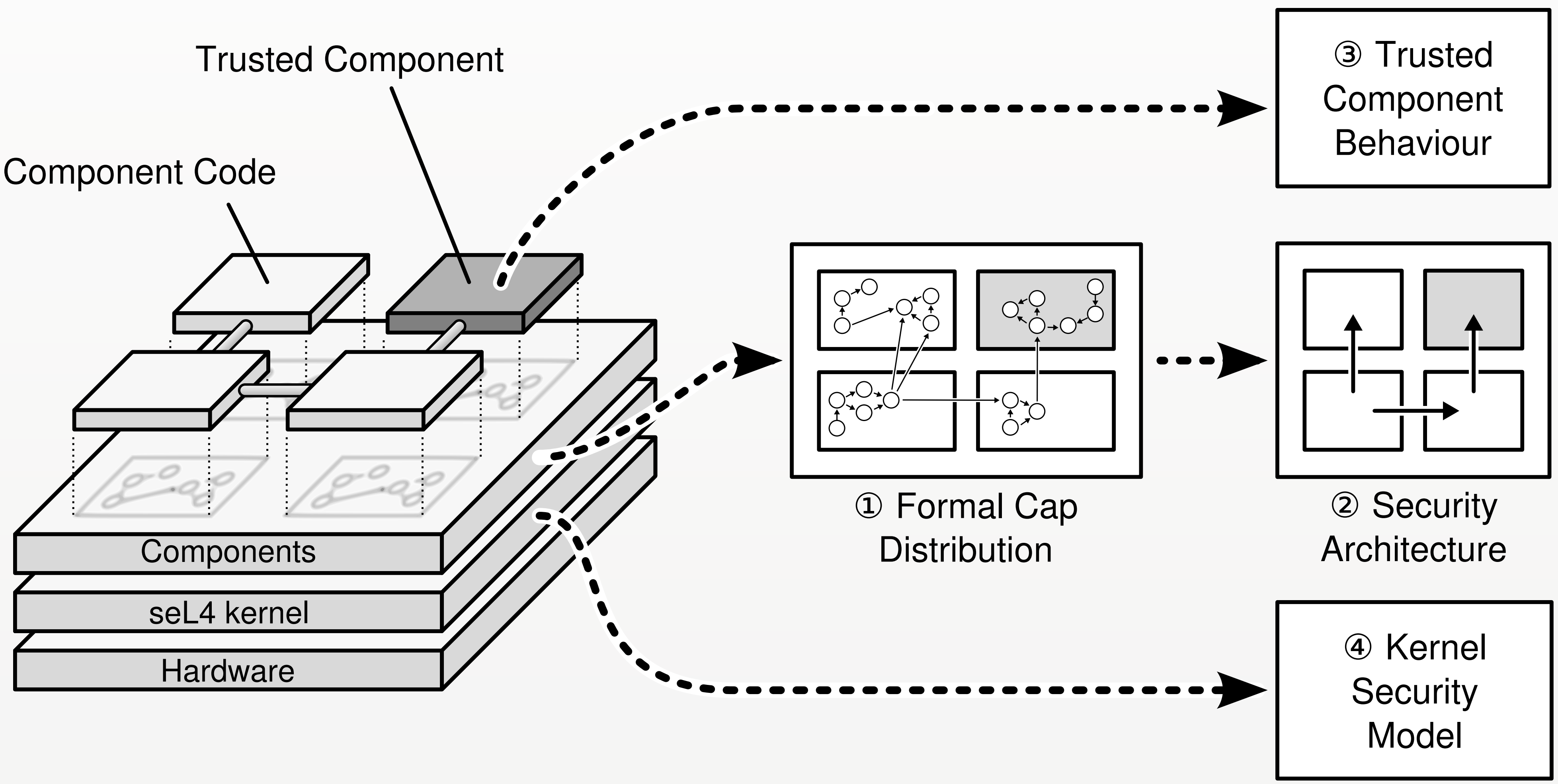

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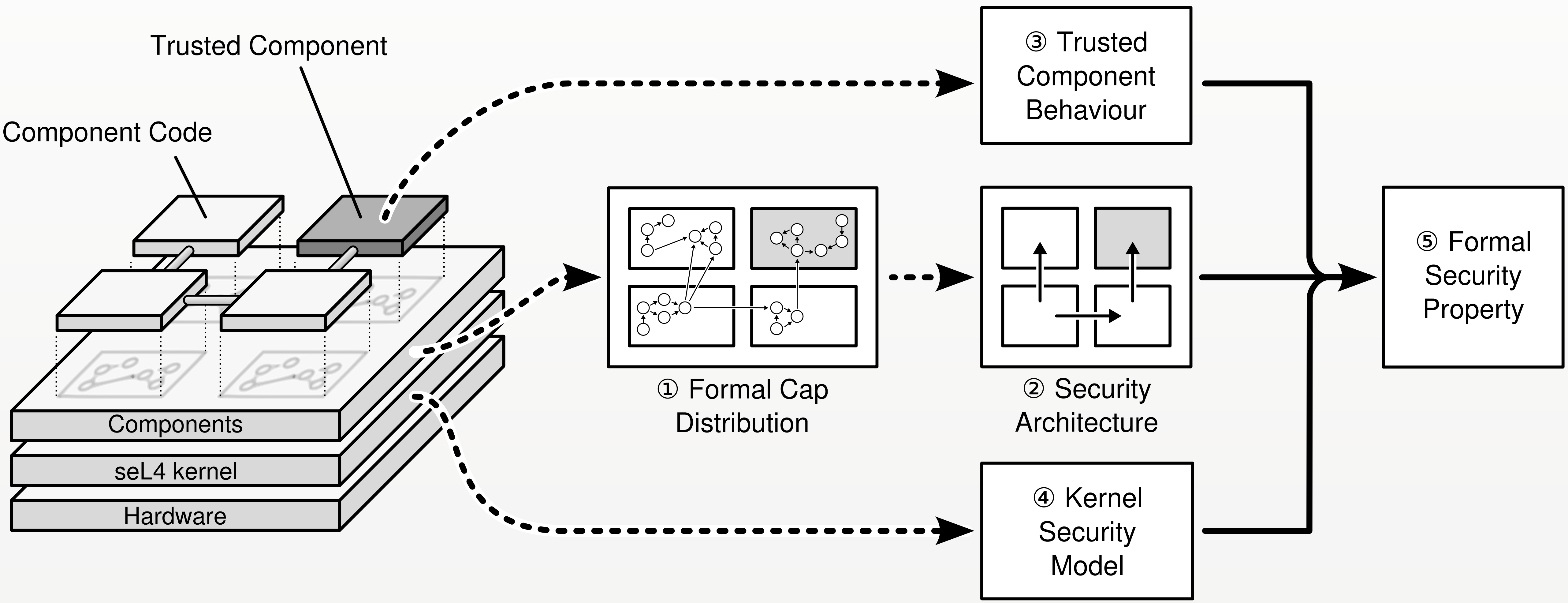
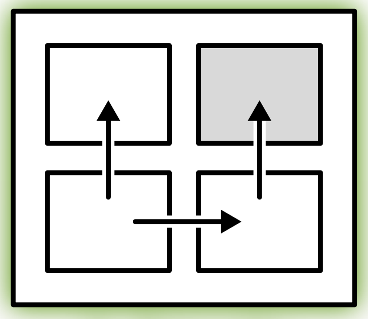


High Level System Model

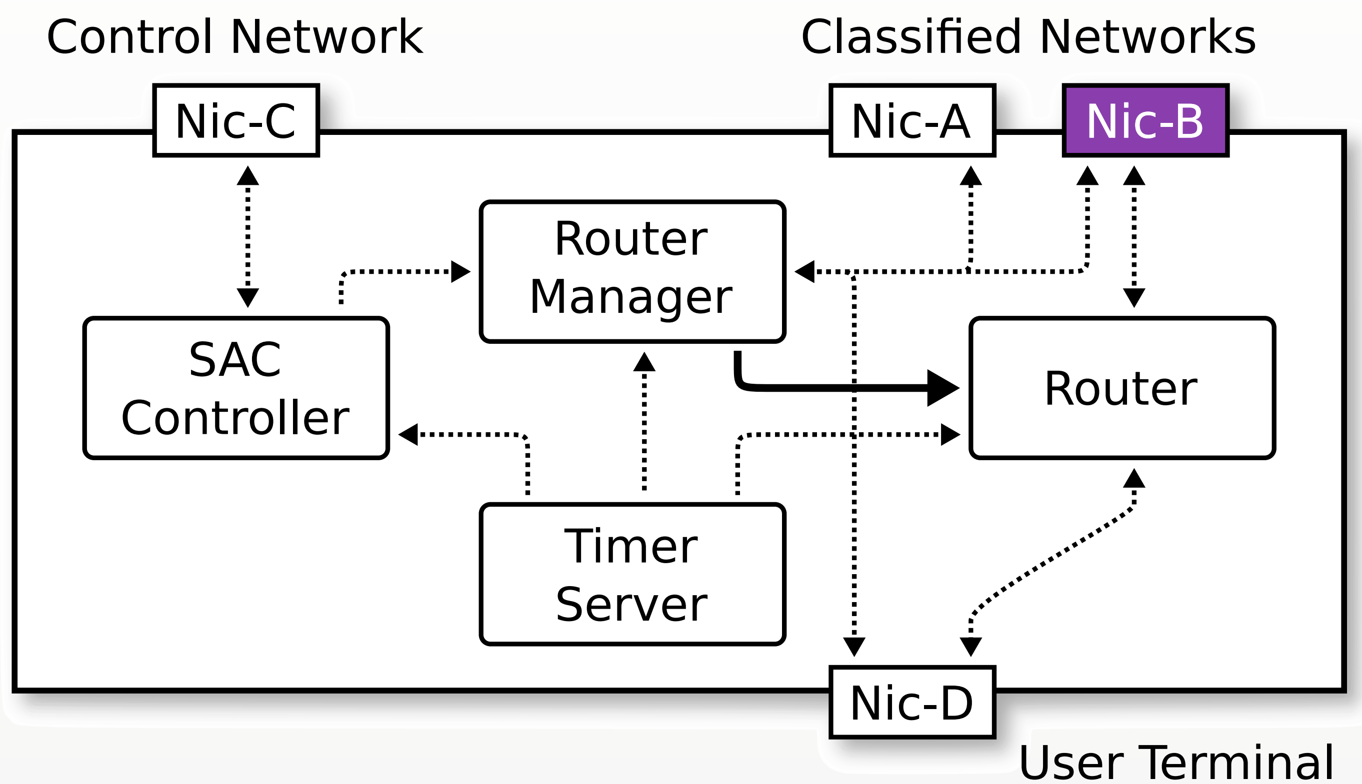


② Security Architecture

③ Trusted Component Behaviour

④ Kernel Security Model

⑤ Formal Security Property

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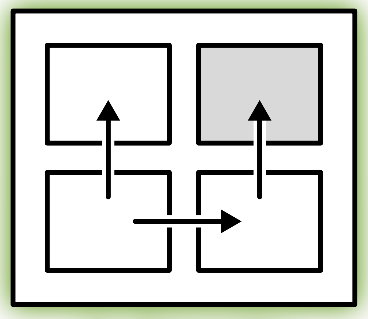

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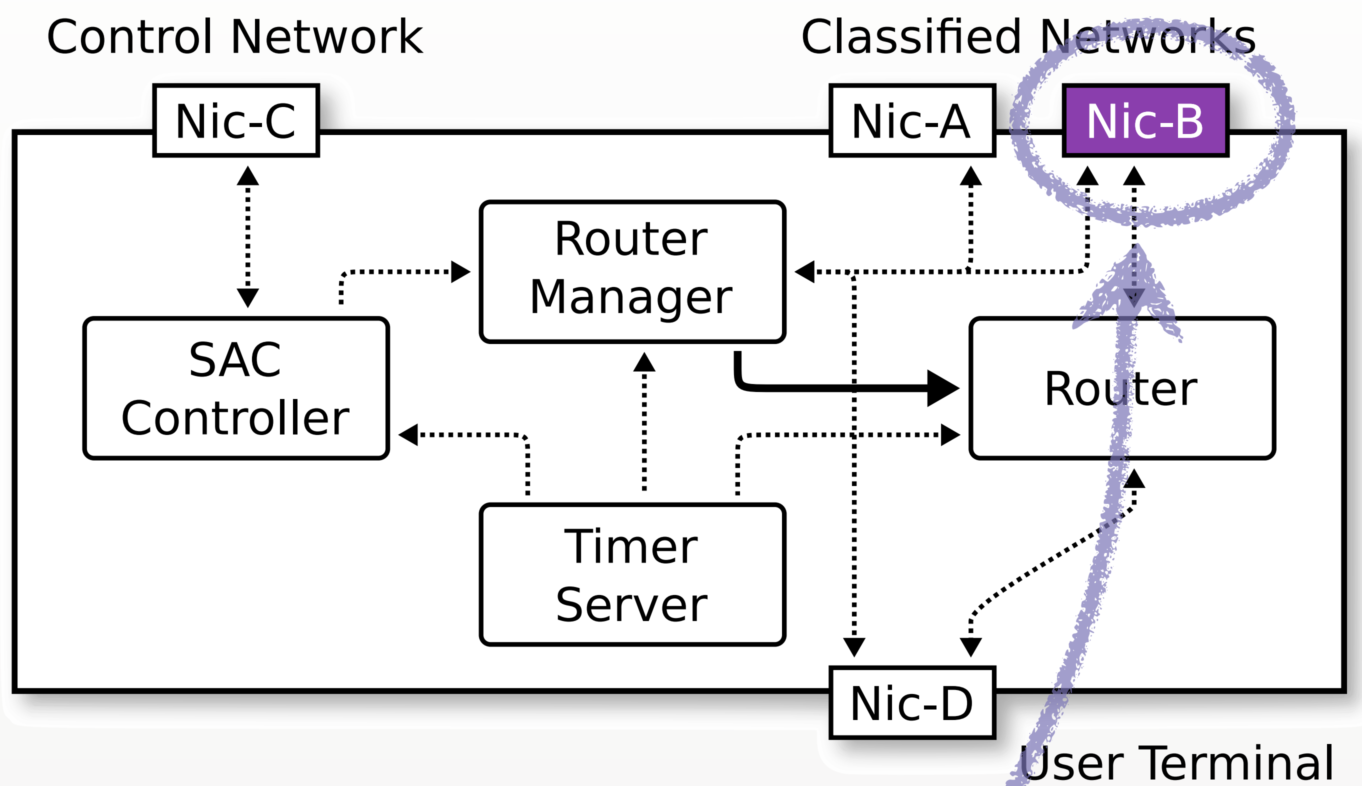


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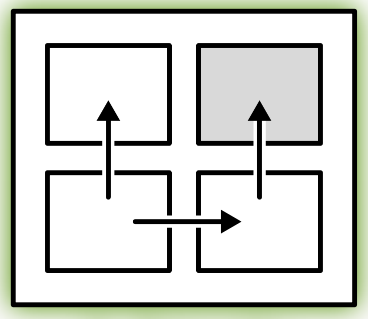

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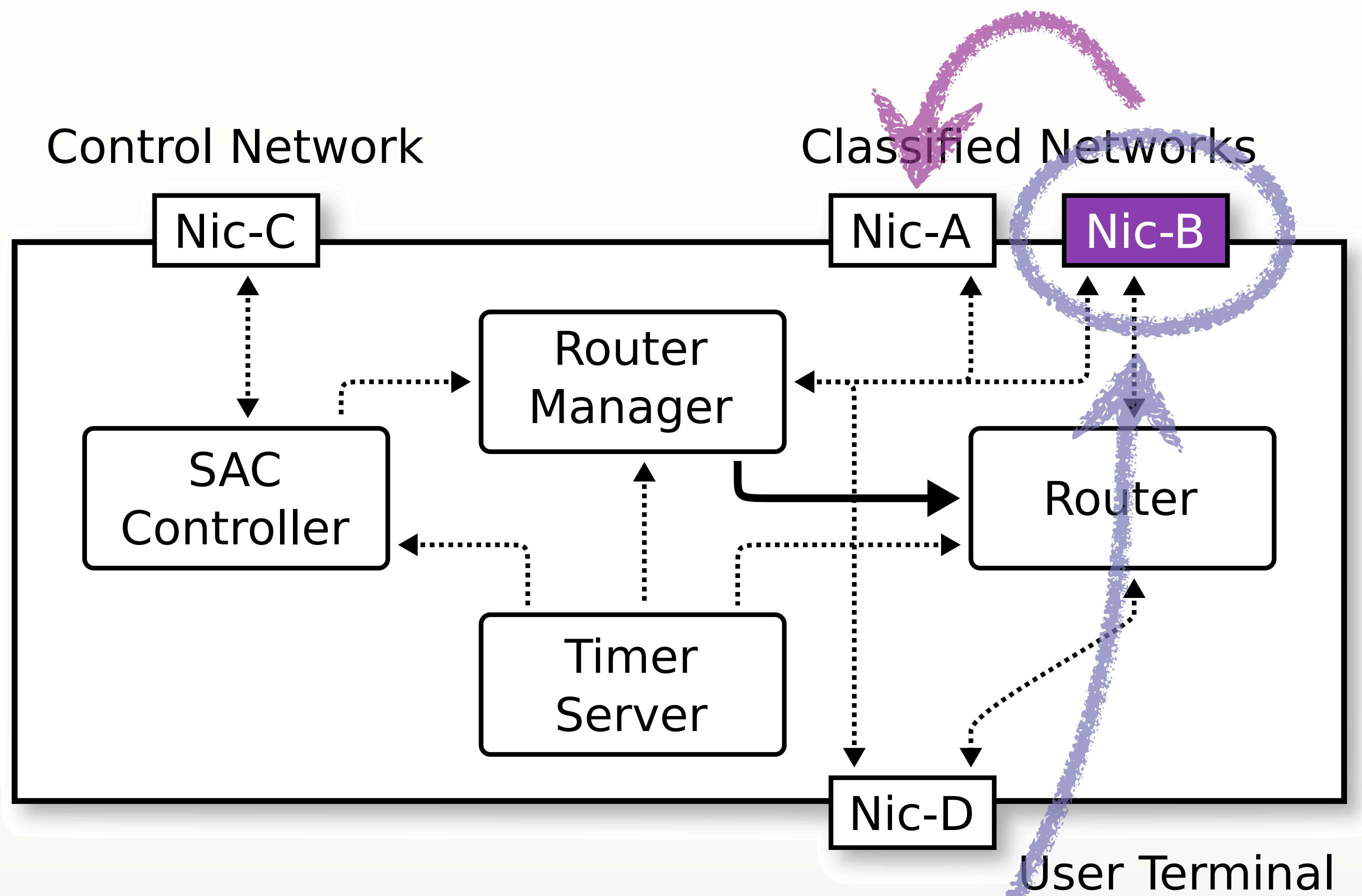


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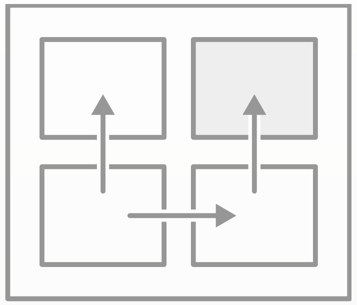

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```
UNTRUSTED_prg ≡ [ AnyLegalOperation ]
```

```
RM_prg ≡
  [ (* 00: Wait for command, delete Router. *)
    SysOp (SysRead cap_R_to_SAC_C),
    SysOp (SysRemoveAll cap_C_to_R),
    SysOp (SysDelete cap_C_to_R),
    SysOp (SysWriteZero cap_RW_to_NIC_D).
    ...
    (* 09: Non-deterministic “goto” *)
    Jump [0, 10, 19],

    (* 10: Setup Router between NIC-A and NIC-D *)
    SysOp (SysCreate cap_C_to_R),
    SysOp (SysNormalWrite cap_RWGC_to_R),
    ...
  ]
```

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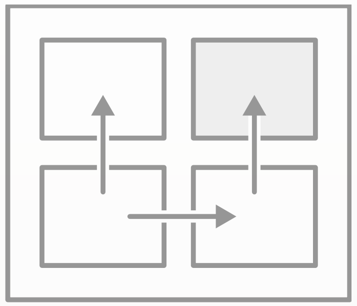

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```
step state e (SysRead c) =
  write_operation (entity c) e state
```

What operations do user system calls perform?

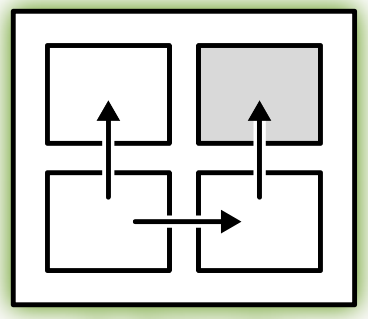
```
legal s e (SysRead cap) =
  (is_entity s e
     ∧ is_entity s (entity cap)
     ∧ cap ∈ entity_caps_in_state s e
     ∧ Read ∈ rights cap)
```

When is a system call allowed by the kernel?

```
write_operation source target ss ≡
  (case (ss target) of
    Some target_entity ⇒
      ss(target ↦ target_entity(
        contaminated :=
            is_contaminated ss target
          ∨ is_contaminated ss source)
  | _ ⇒ ss)
```

What effect do system calls have?

High Level System Model



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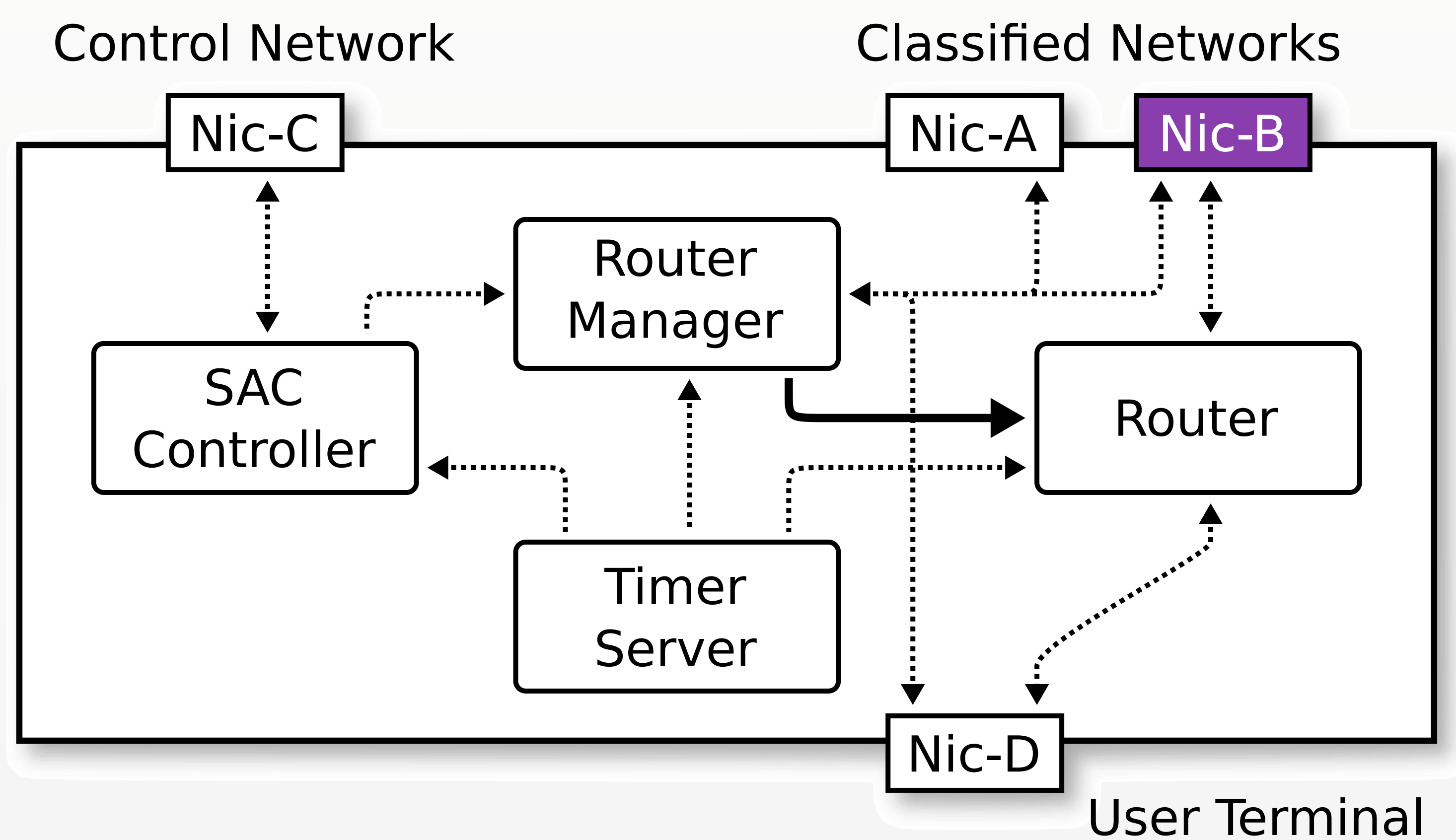

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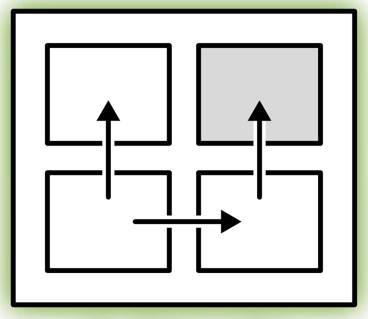

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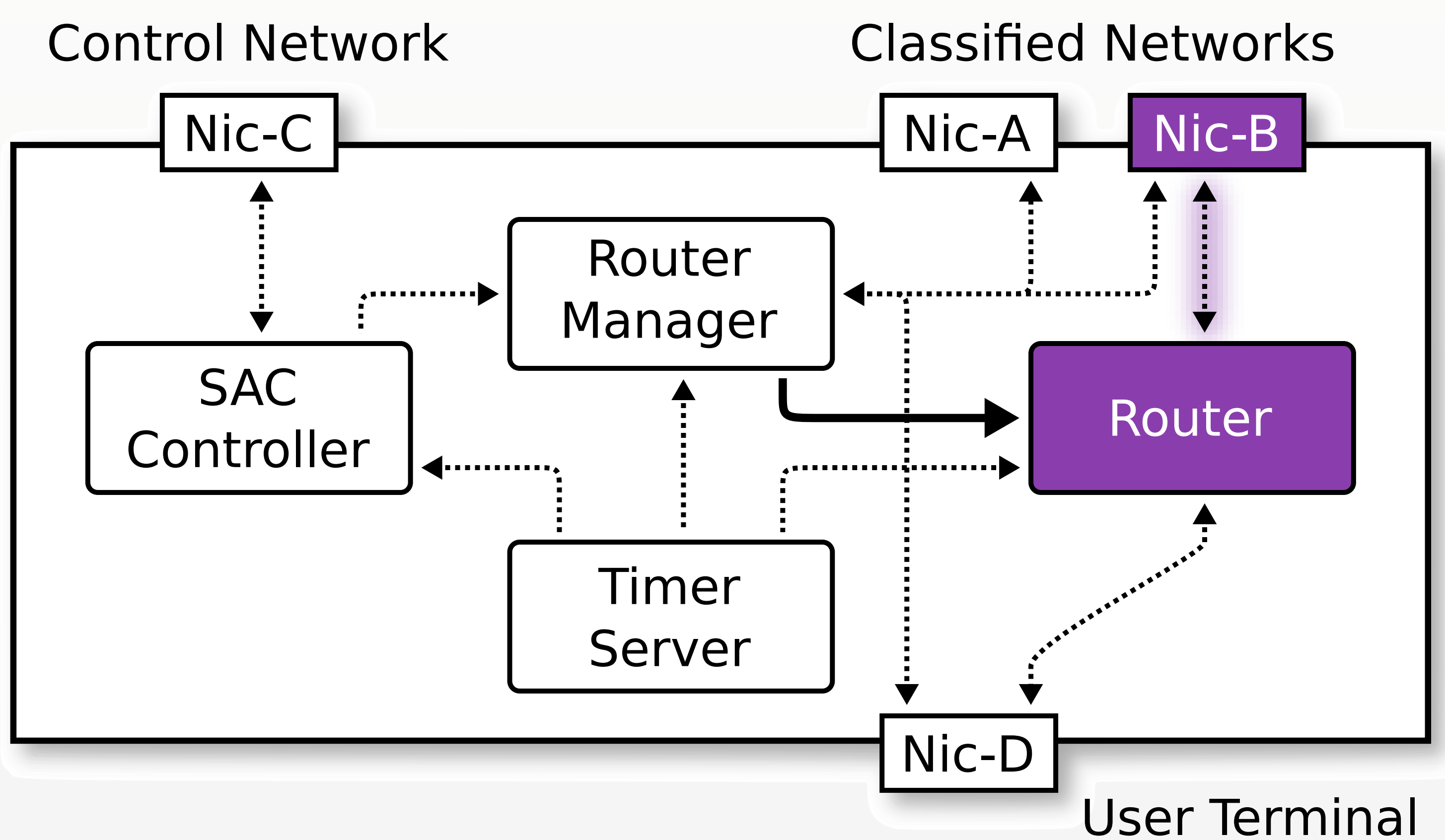

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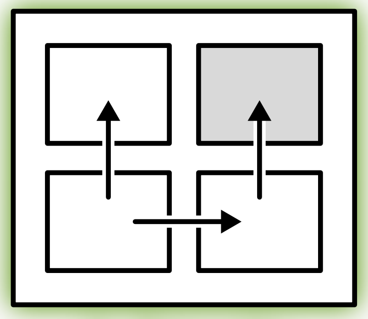

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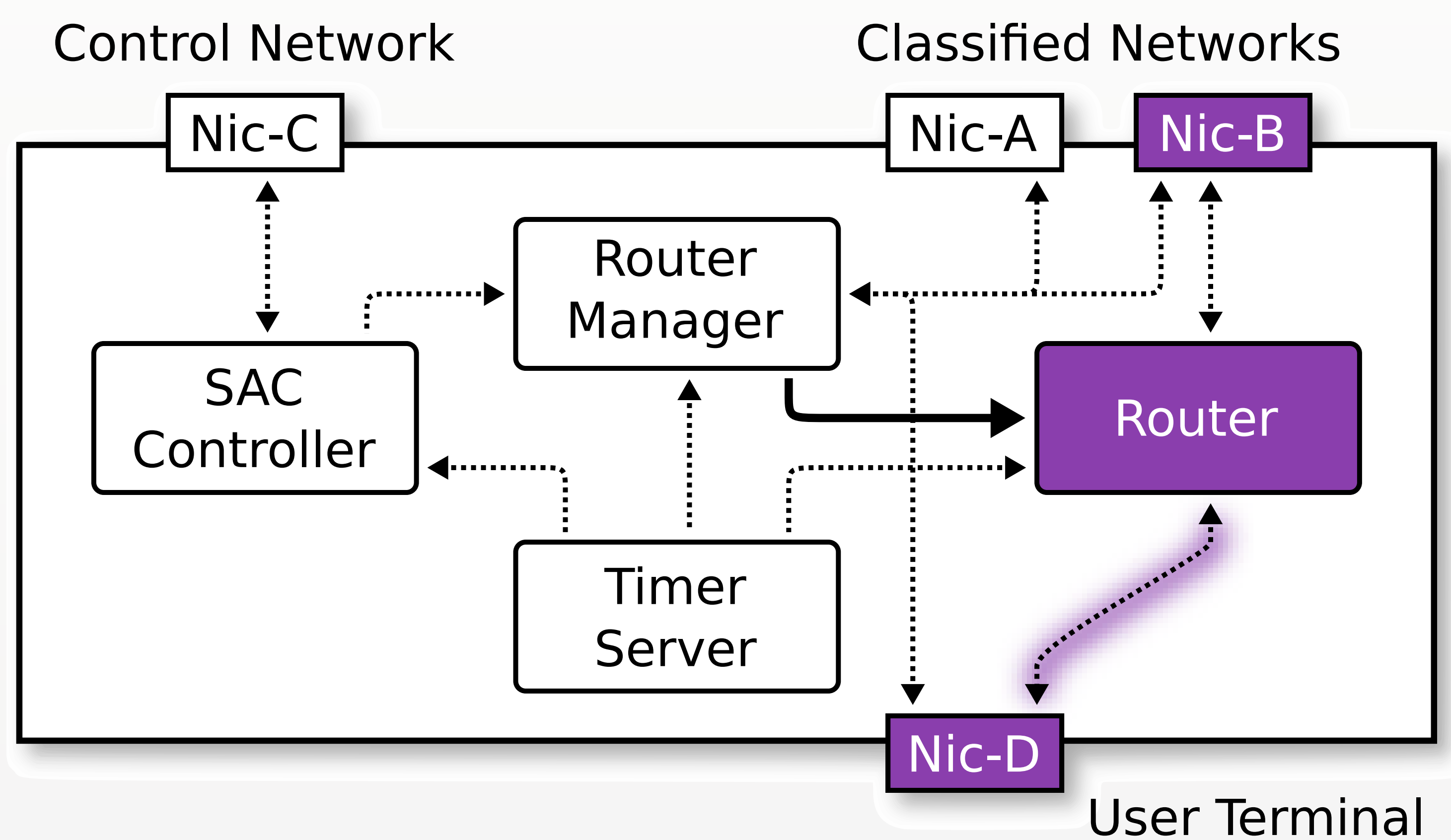

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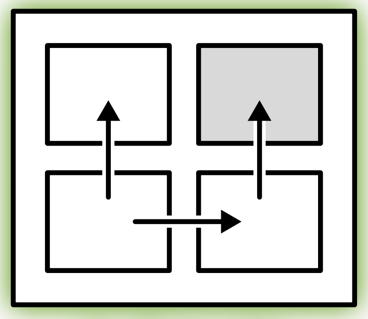

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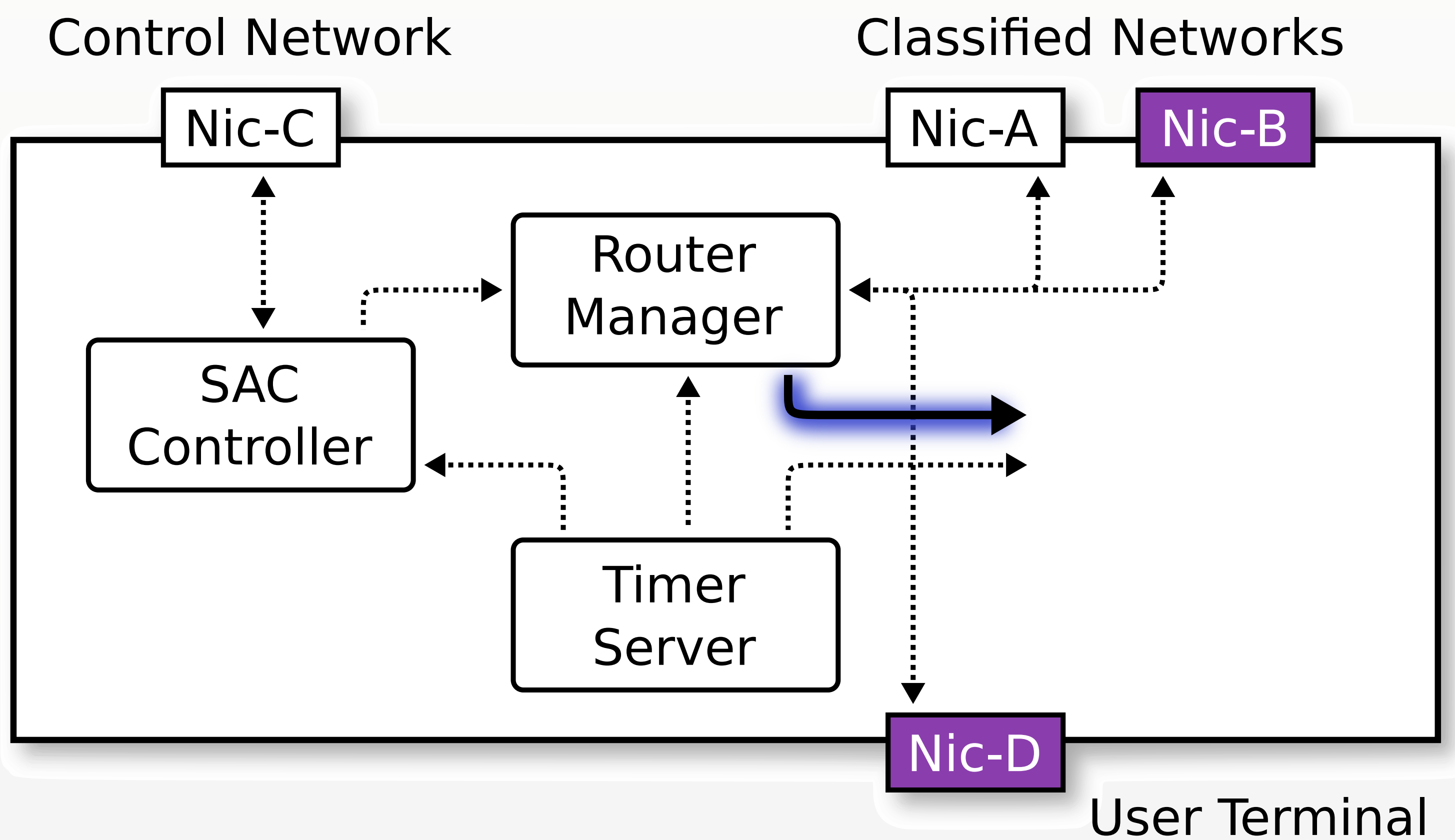

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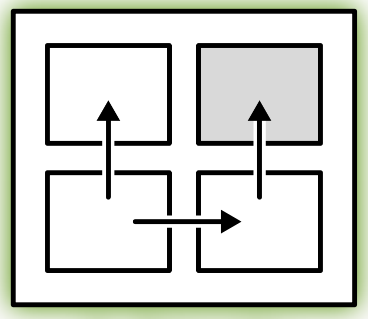

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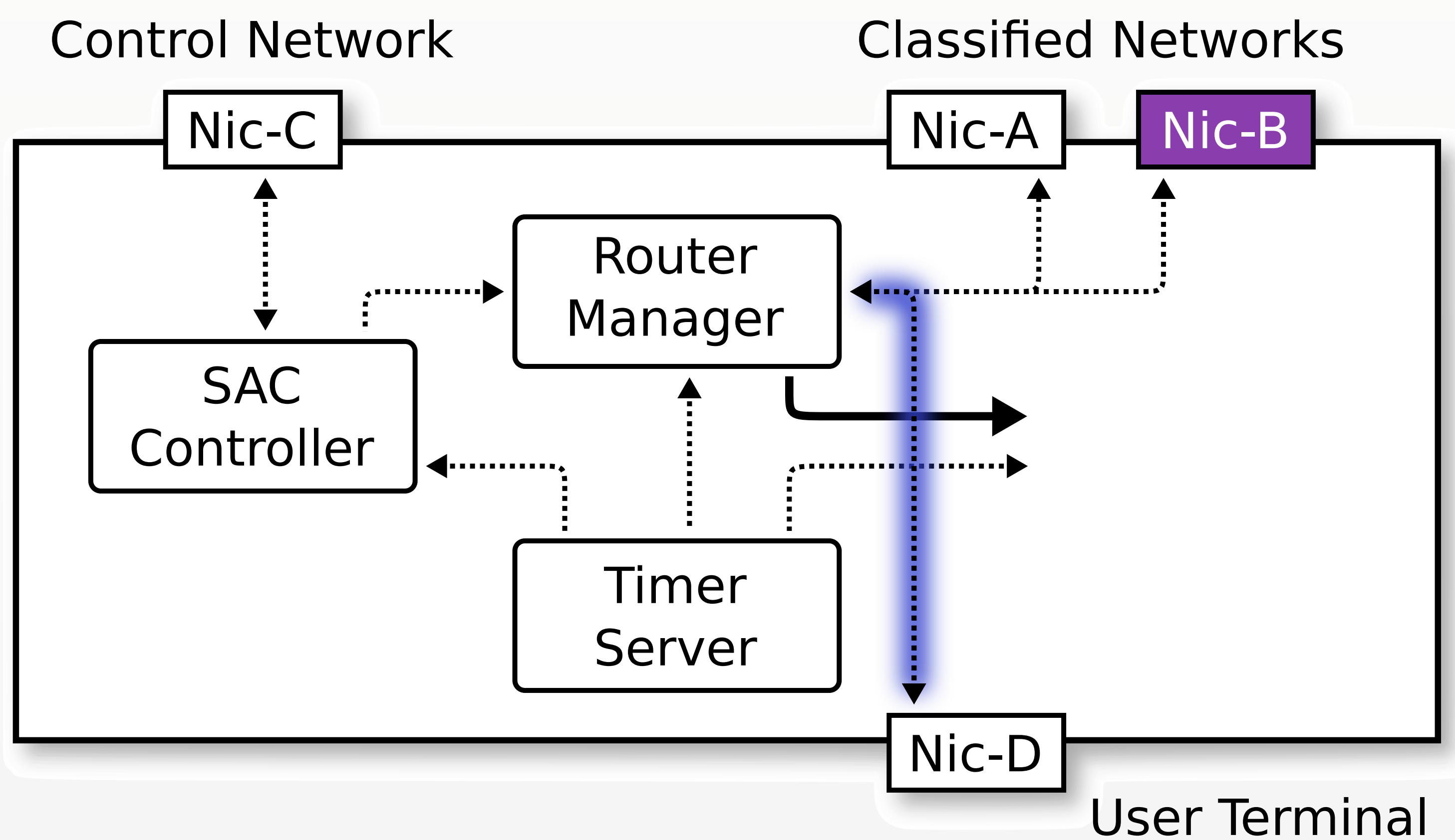

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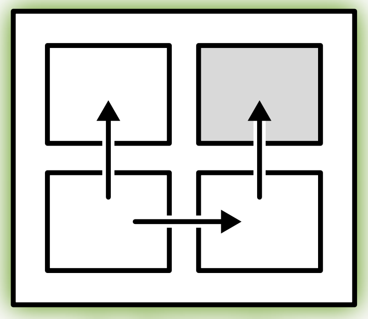

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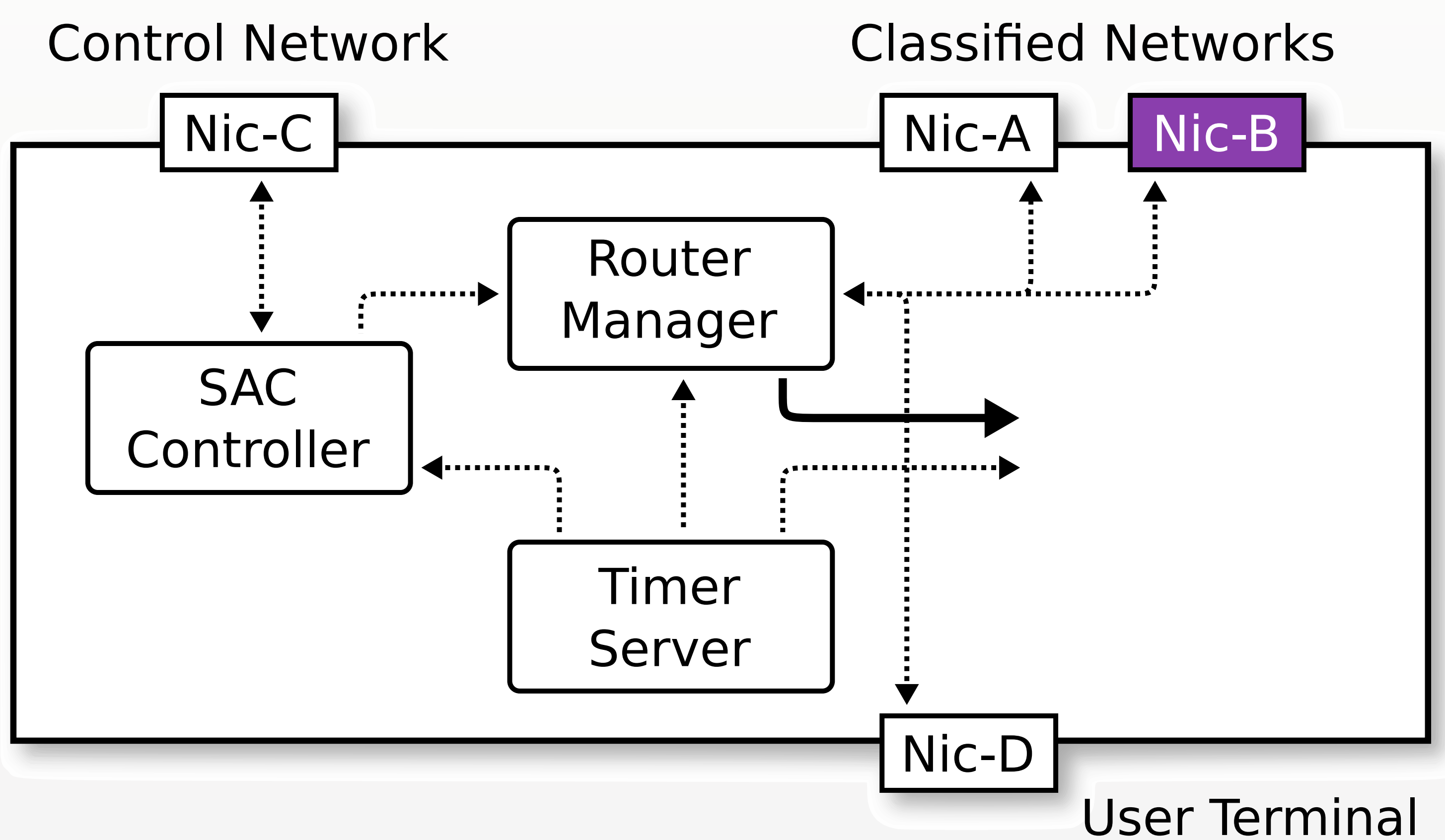

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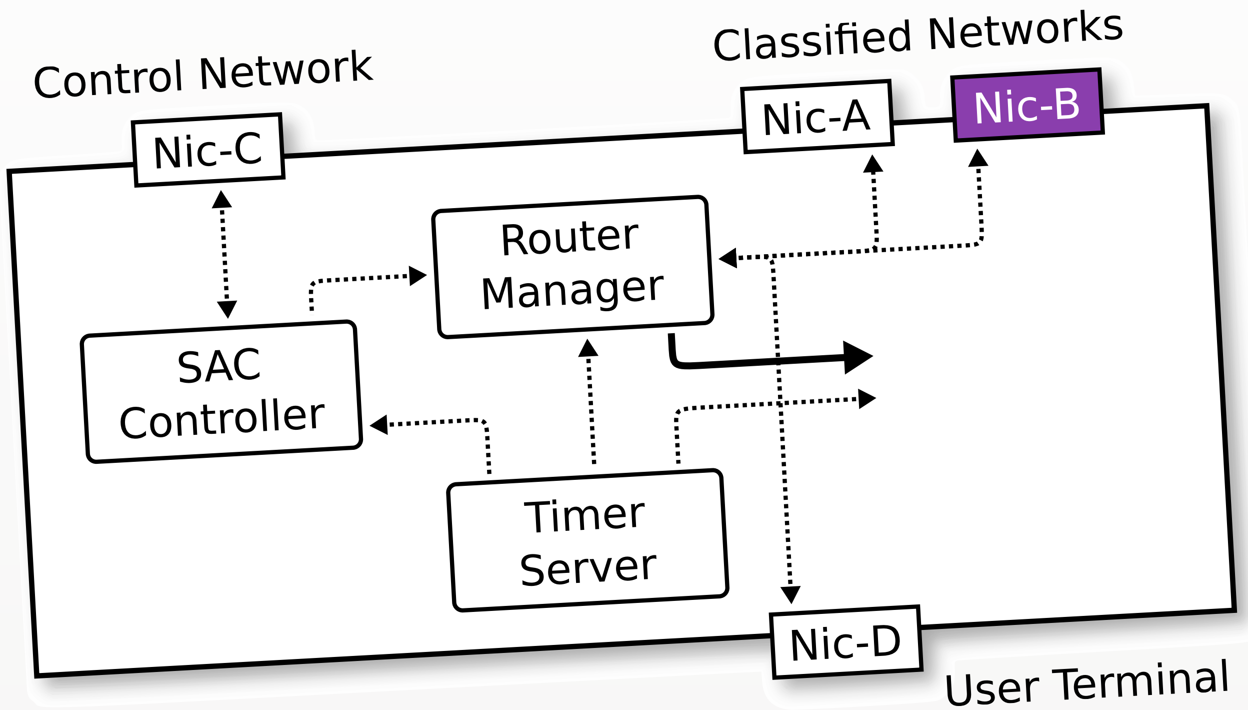
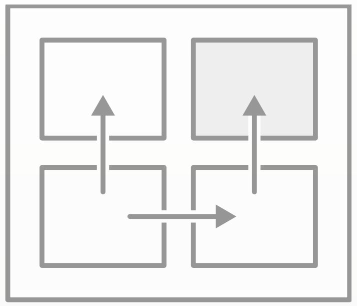
⑤ Formal Security Property




```
theorem sac_is_secure:
  (SAC-startup →* ss) ⟹ ¬ is_contaminated (sac-entity-ss) NicA
```

High Level System Model



② Security Architecture

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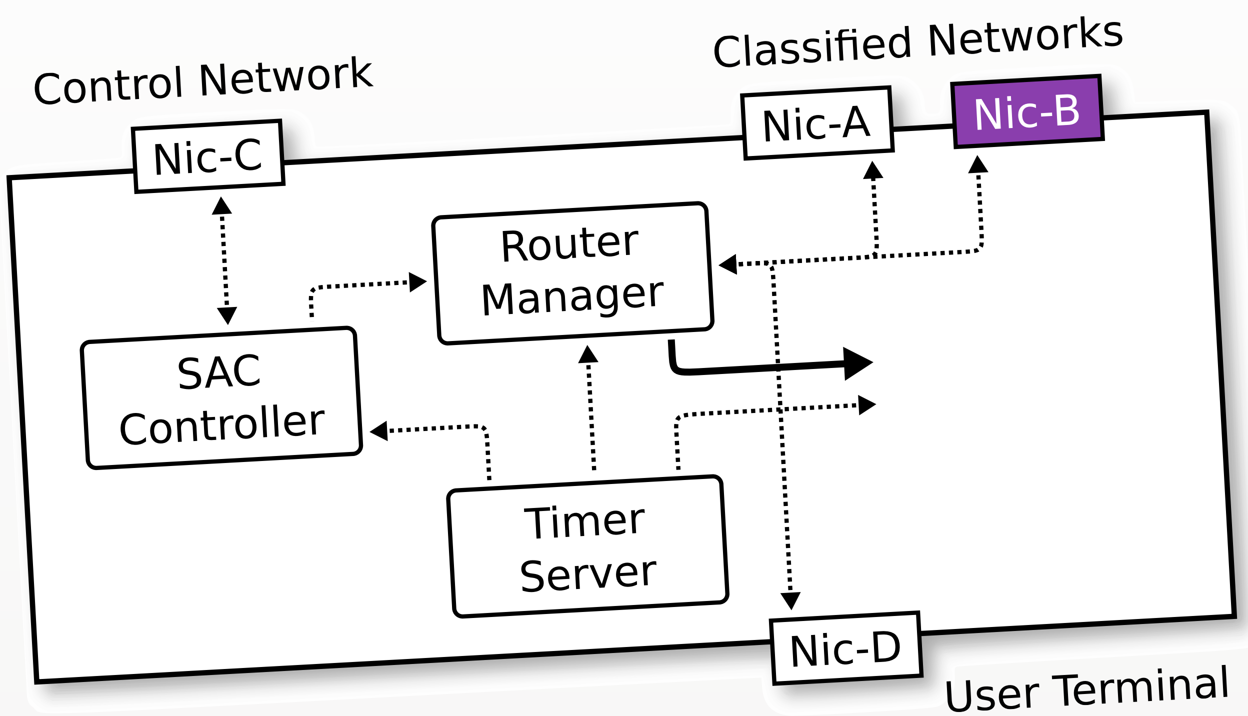


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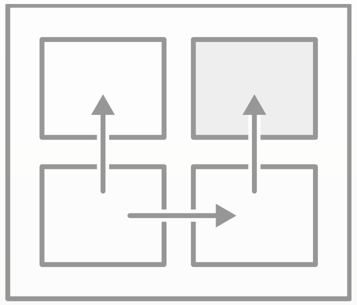
High Level System Model

NICTA



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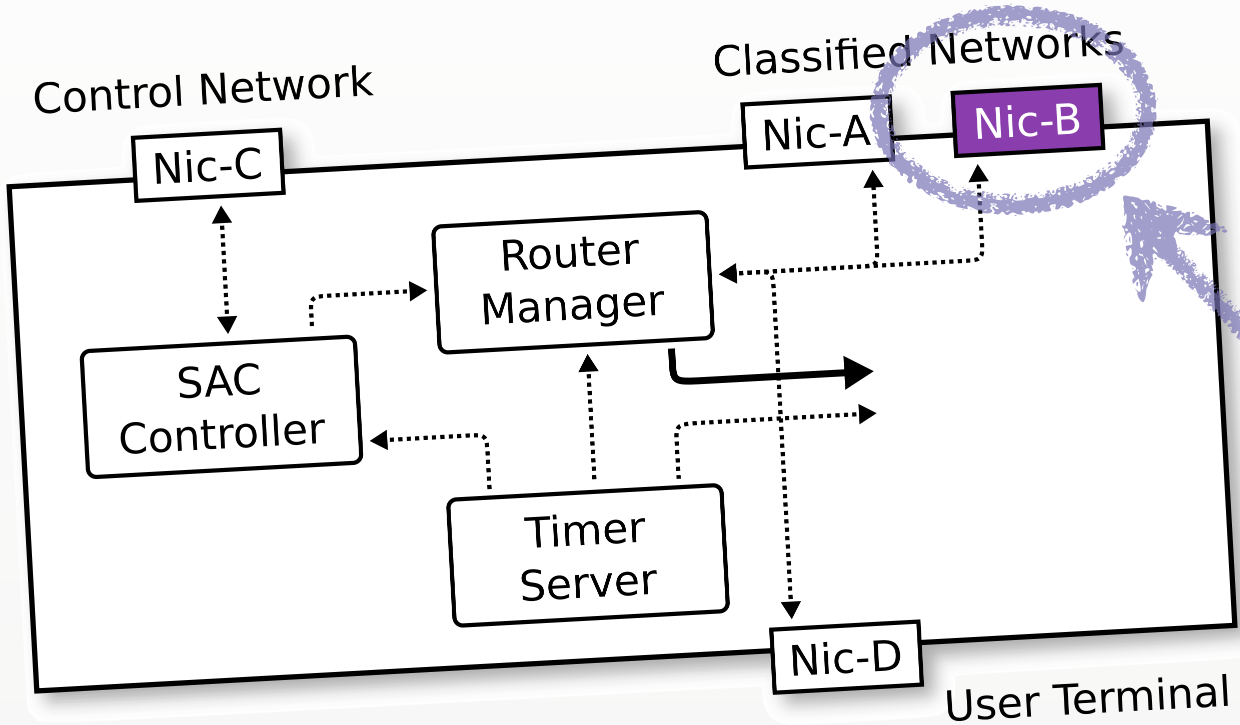


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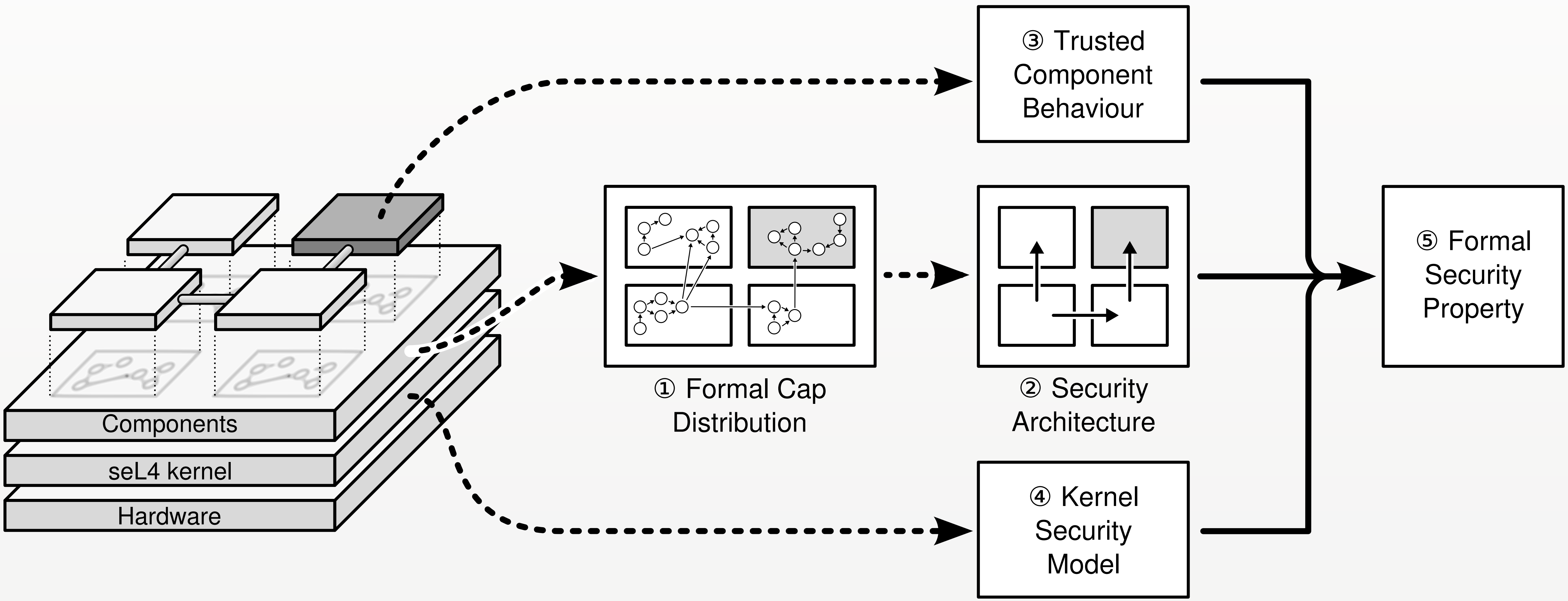
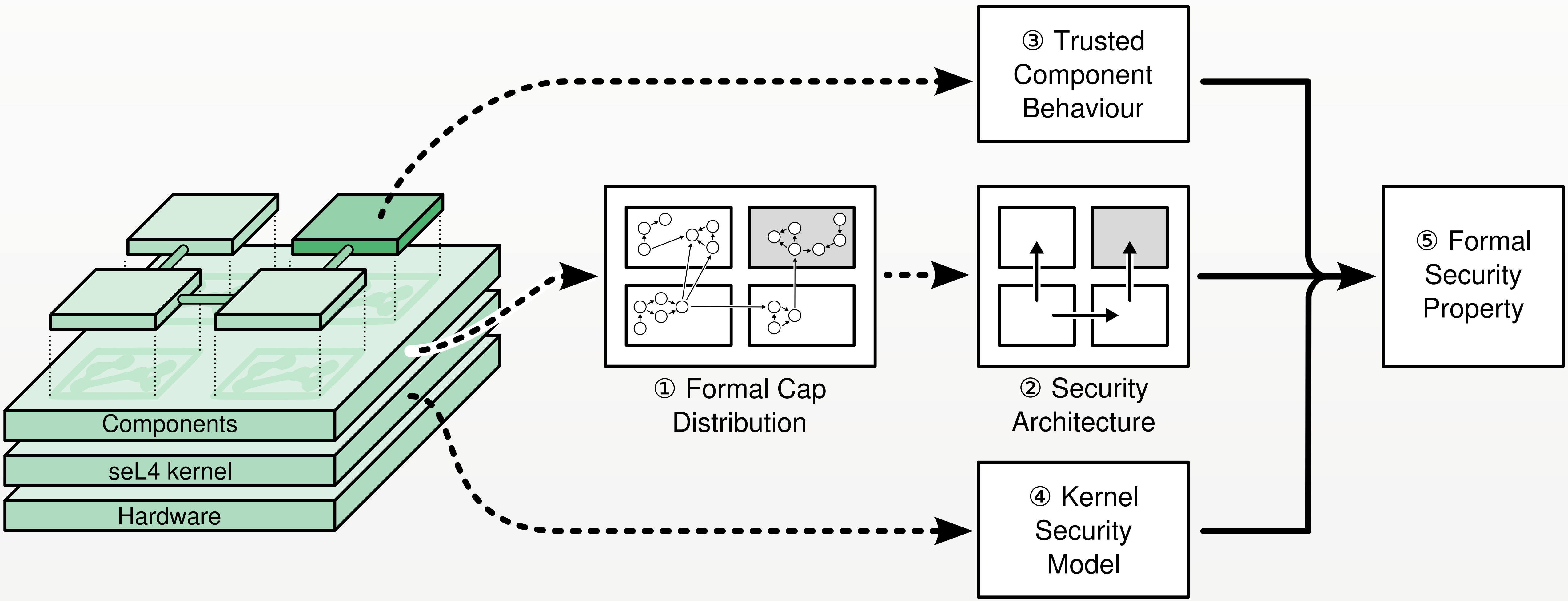
Progress



③ Trusted Component Behaviour
Components
seL4 kernel
Hardware
① Formal Cap Distribution
② Security Architecture
⑤ Formal Security Property
④ Kernel Security Model

Progress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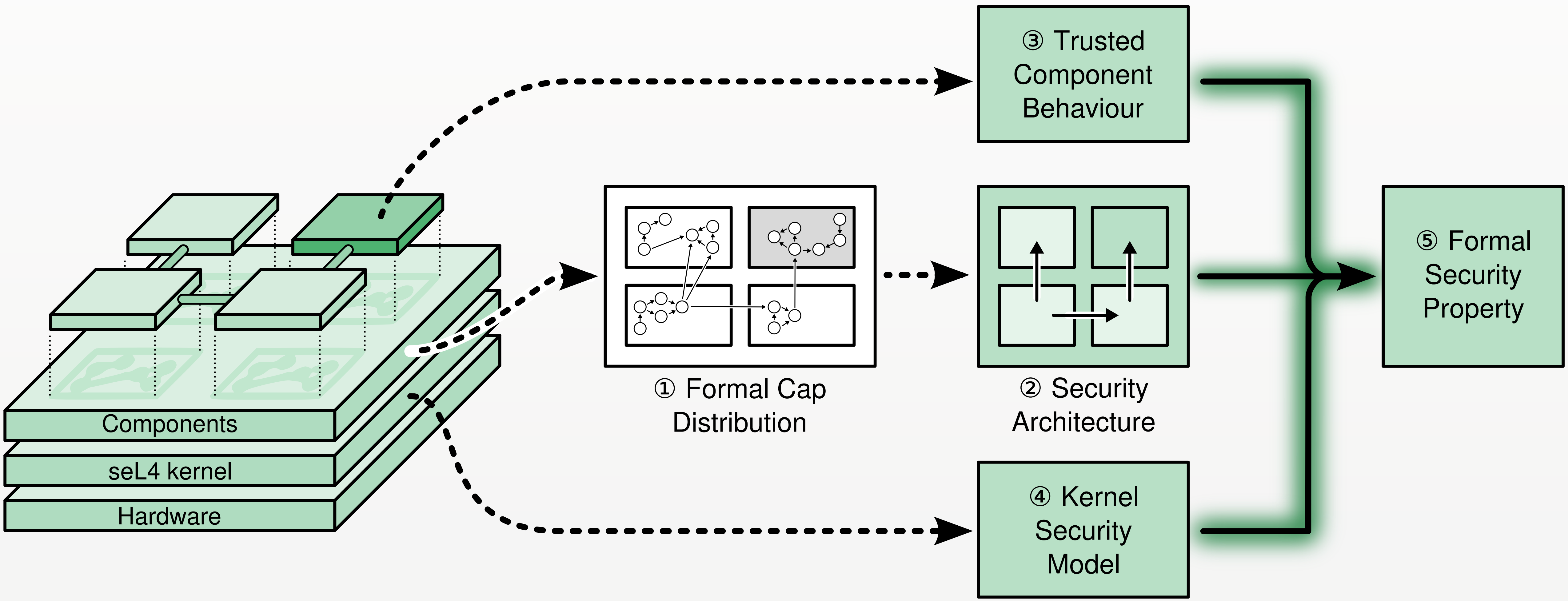

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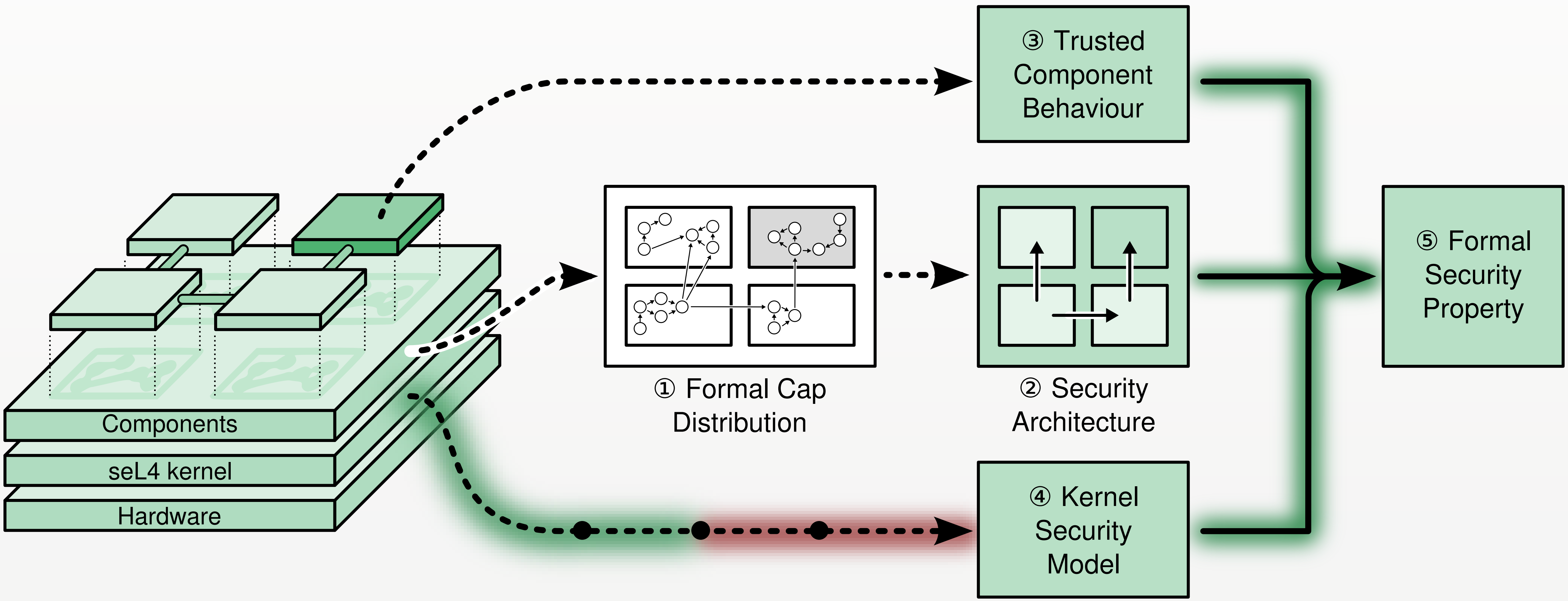

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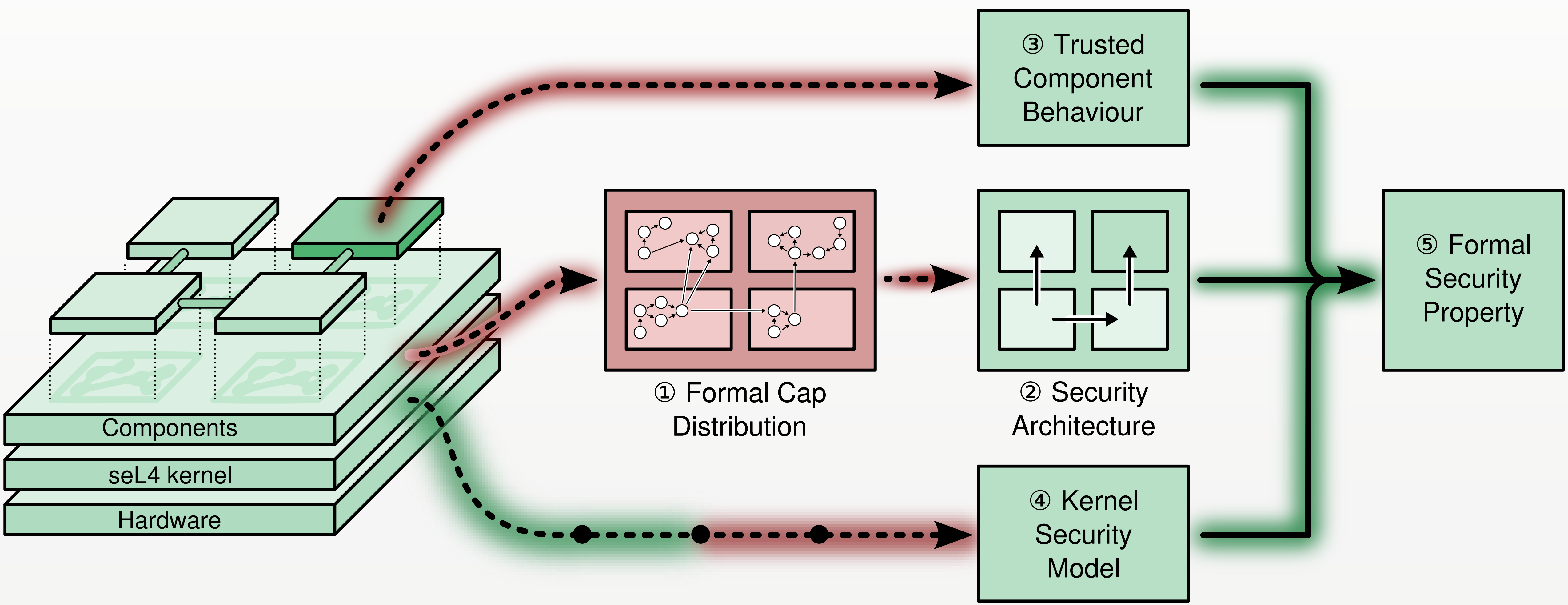

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Conclusion

NICTA

- Full system verification of modern systems infeasible
  - But verification of specific, targeted properties feasible
- Presented a framework for proving security
  - Break code into components, avoid needing to trust the bulk of our functionality
  - Formally verify components capable of violating desired property
- Built SAC as a case-study
  - Uses seL4 microkernel as a secure foundation
  - Showed a model of the system is secure
- Ongoing work is to join security model with existing seL4 proof

Thank You