Carnegie Mellon
SCHOOL OF COMPUTER SCIENCE

Session-Typed Concurrent Contracts

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Sorting Process

Sorting Process

← 3

Sorting Process

← 3

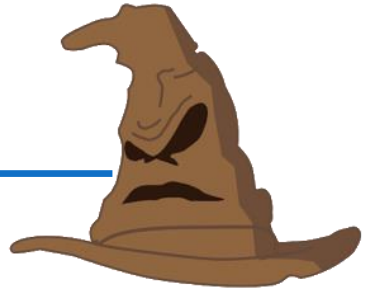
← 5

Sorting Process

← 3

← 5

← 4



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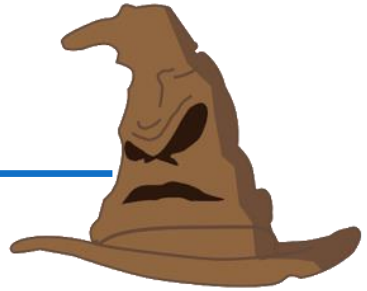
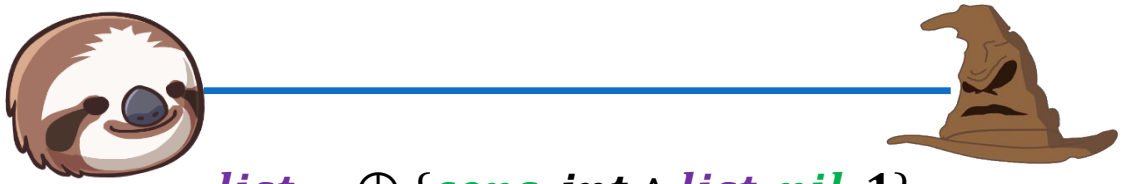


Session Types?!



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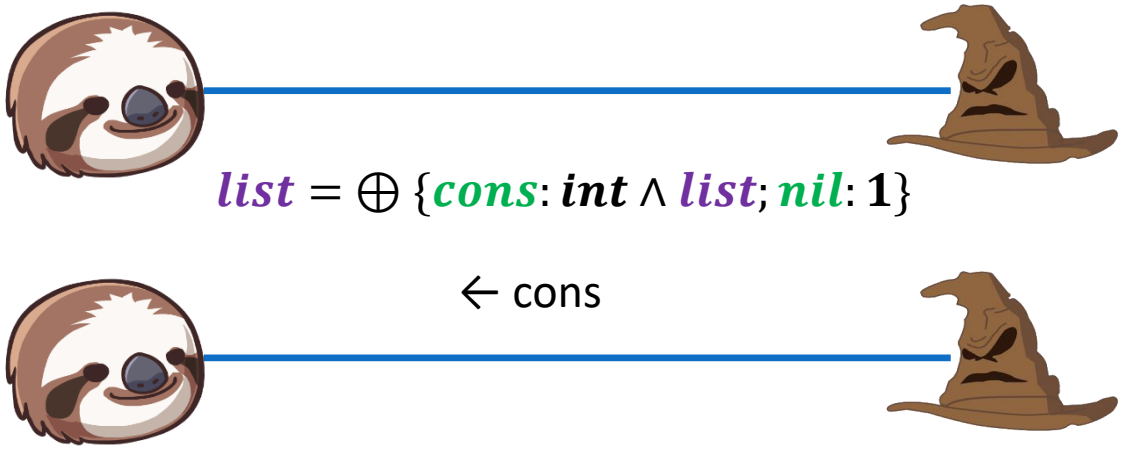

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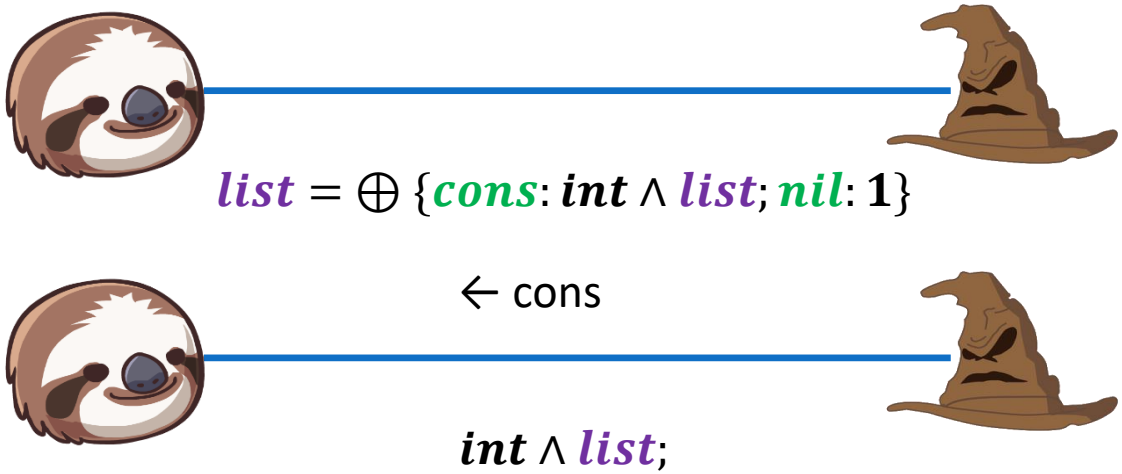

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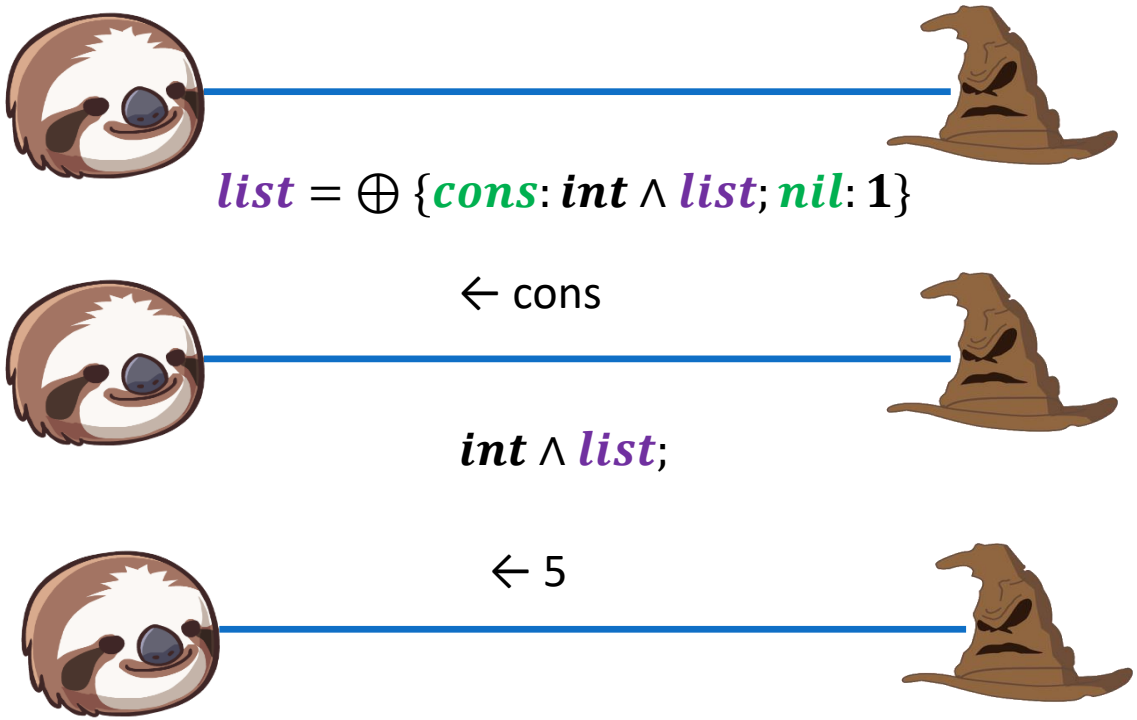

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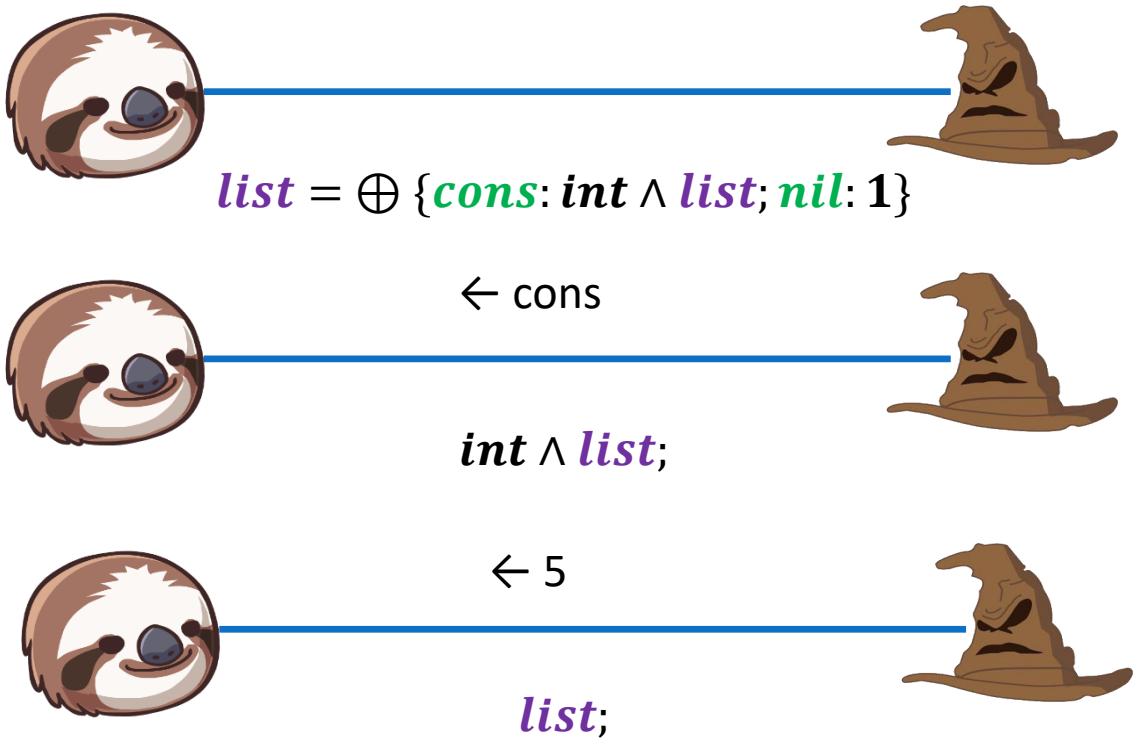
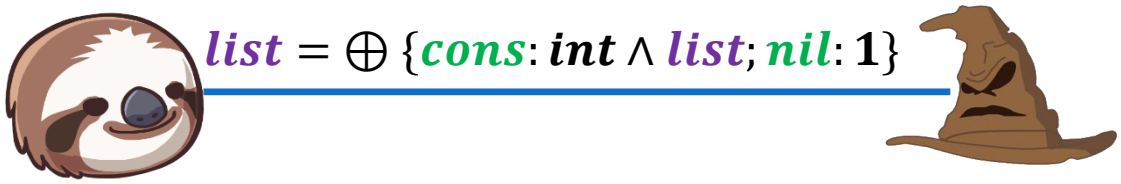


Session Types as Contracts

- Session types prescribe communication contracts between processes
- Dynamically typechecked because processes are untrusted
- Prior work (POPL 2016) on monitoring and blame assignment

Sorting Contract

Contract we have:



Contract we want:

All received integers are in ascending order

Challenge

How do we dynamically monitor contracts that cannot be expressed as session type?

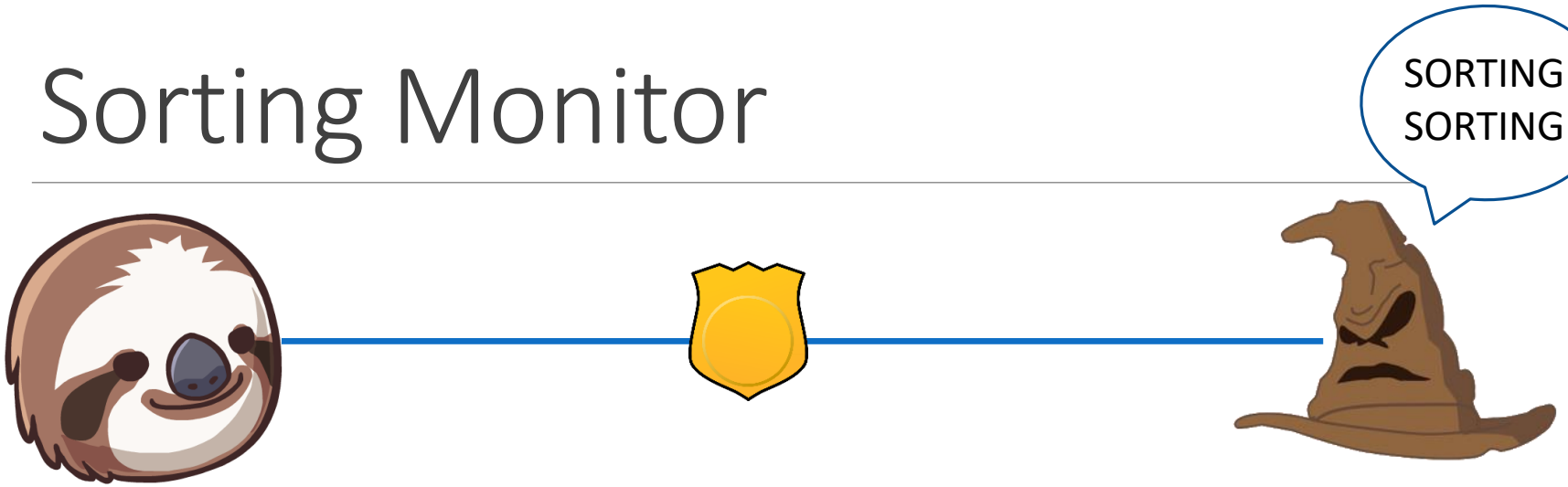
Contributions

- Partial-identity processes that monitor stateful contracts dynamically
- Monitor generation from type refinements
- Method for verifying that monitors are partial identities

Partial Identity Monitors!

- Processes written in the same language as all other code
- Abort if contract is violated, otherwise are transparent
- Check properties by using internal state

Sorting Monitor



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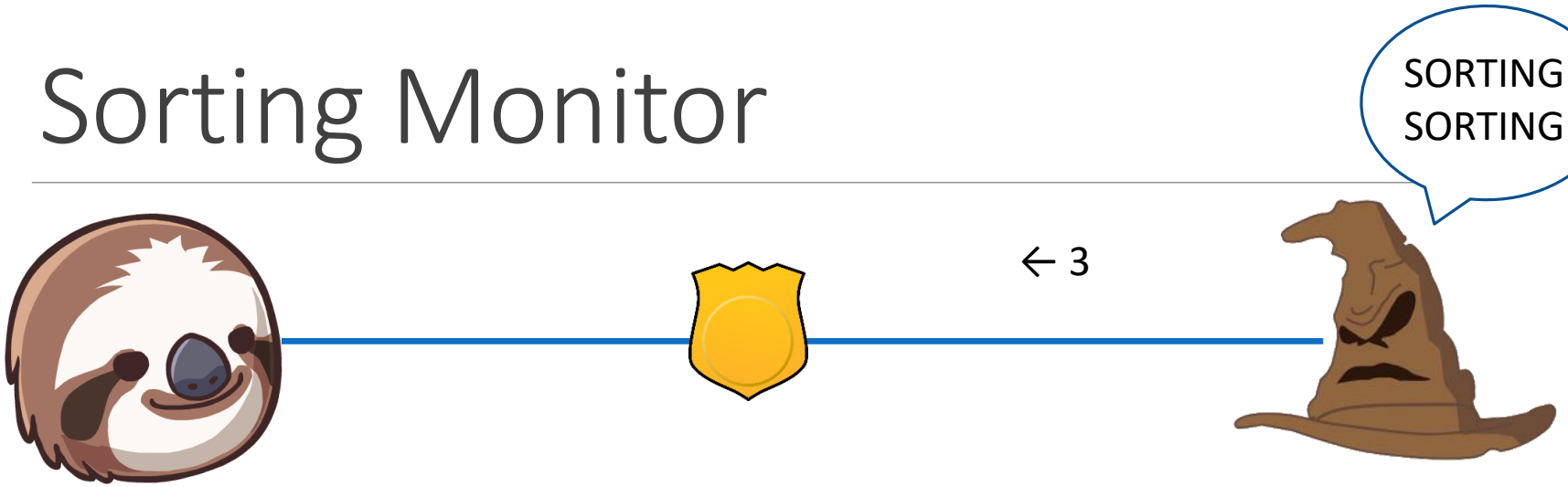

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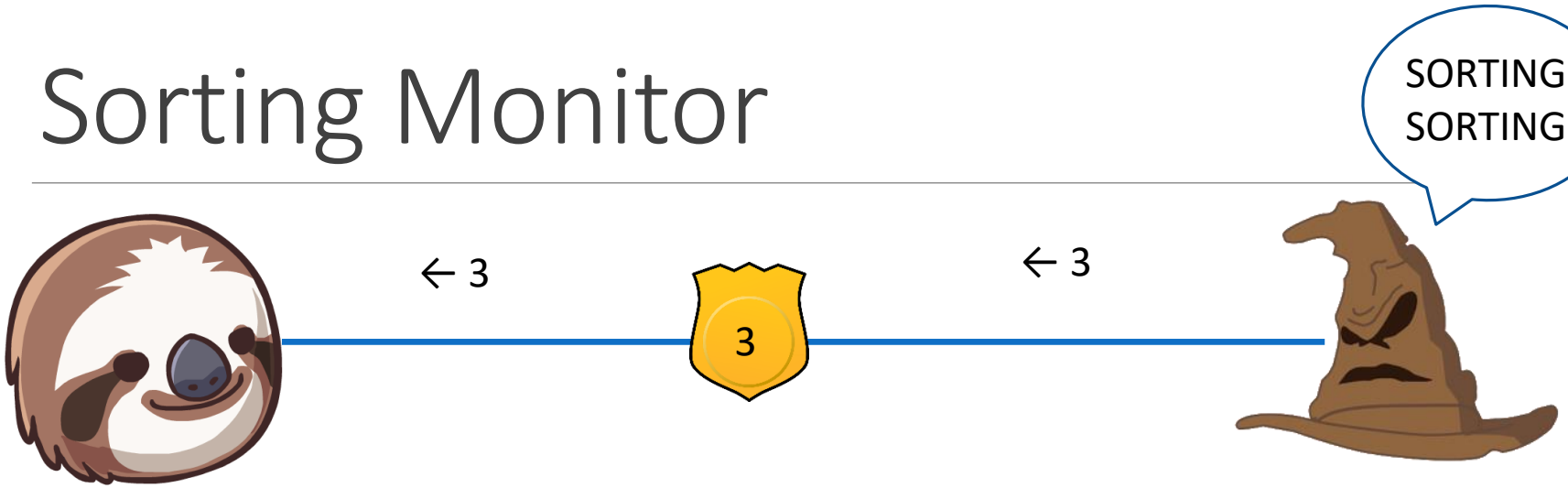

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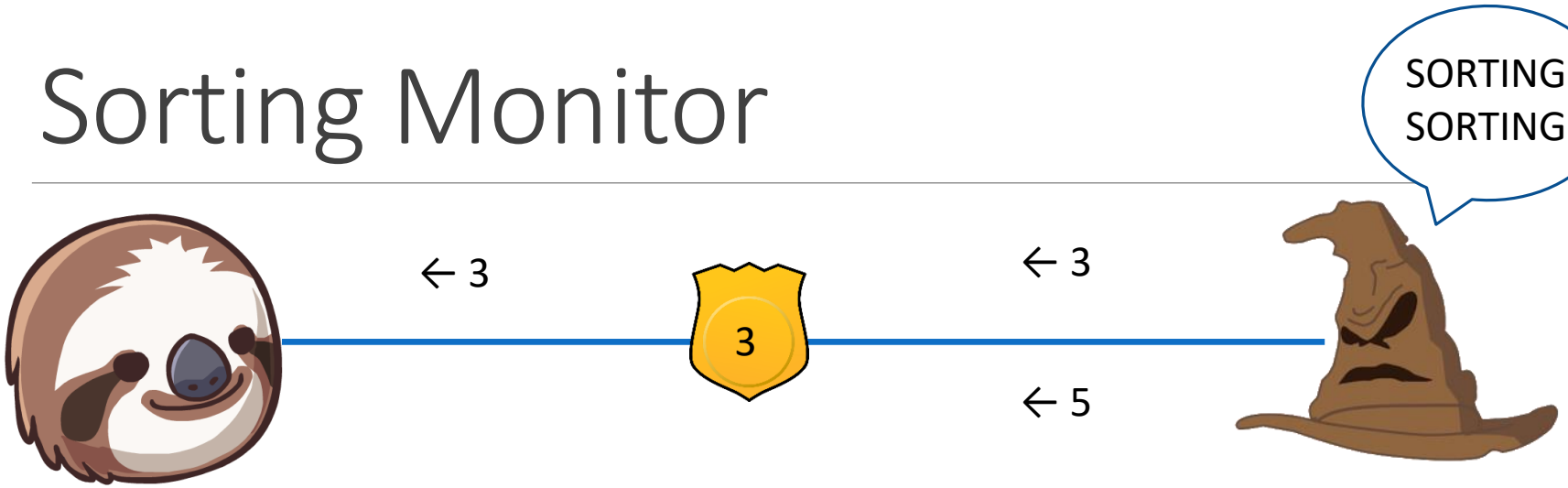

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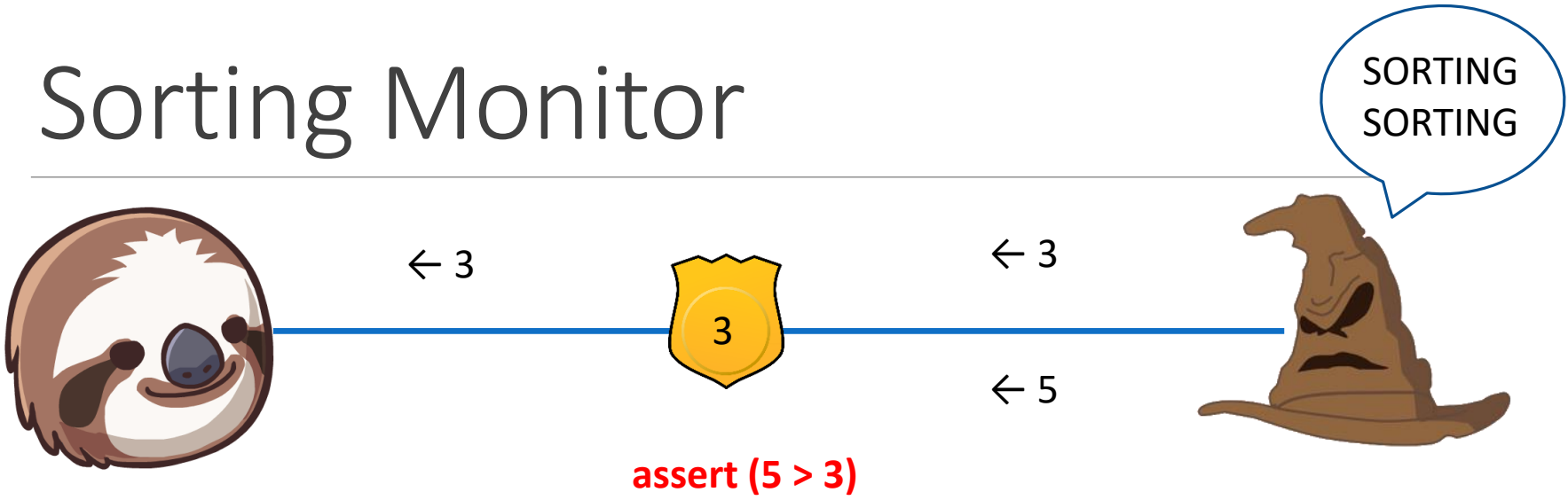

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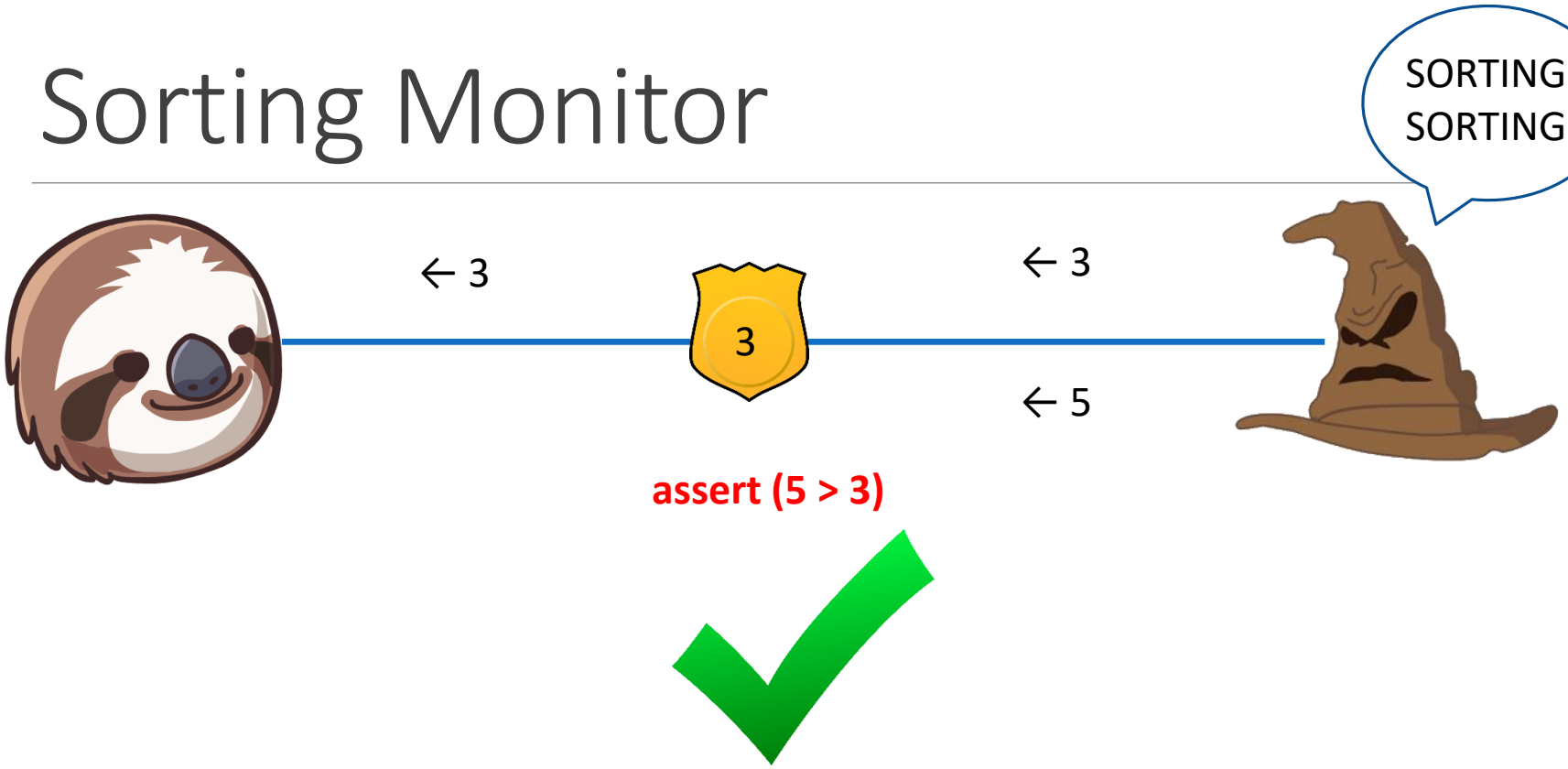

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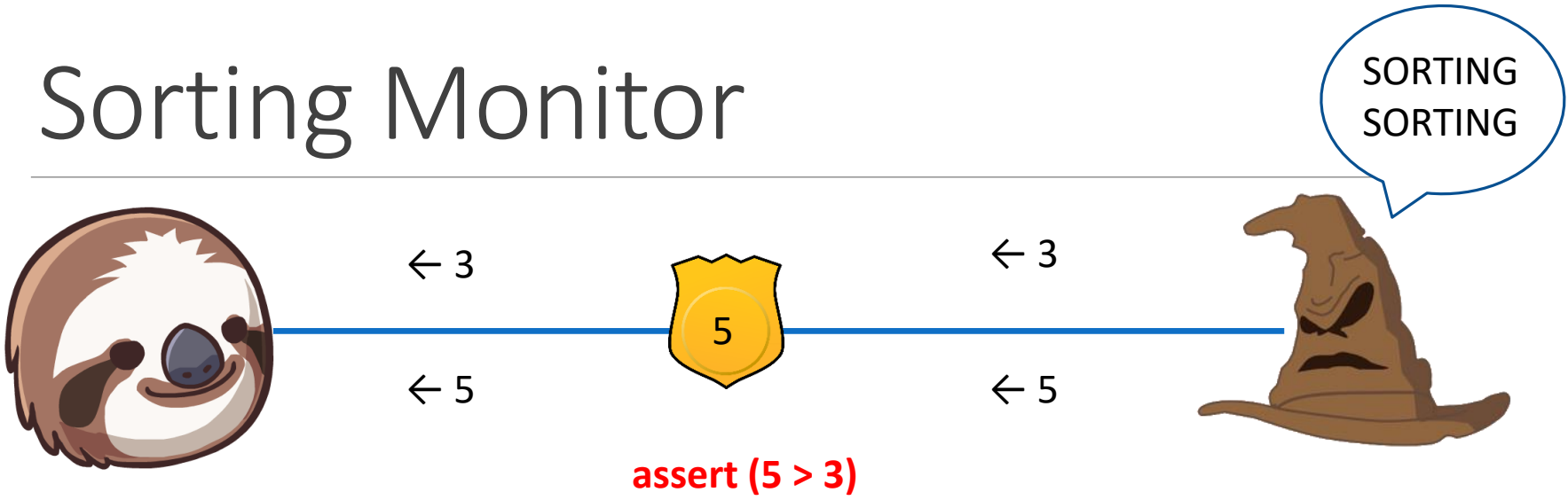

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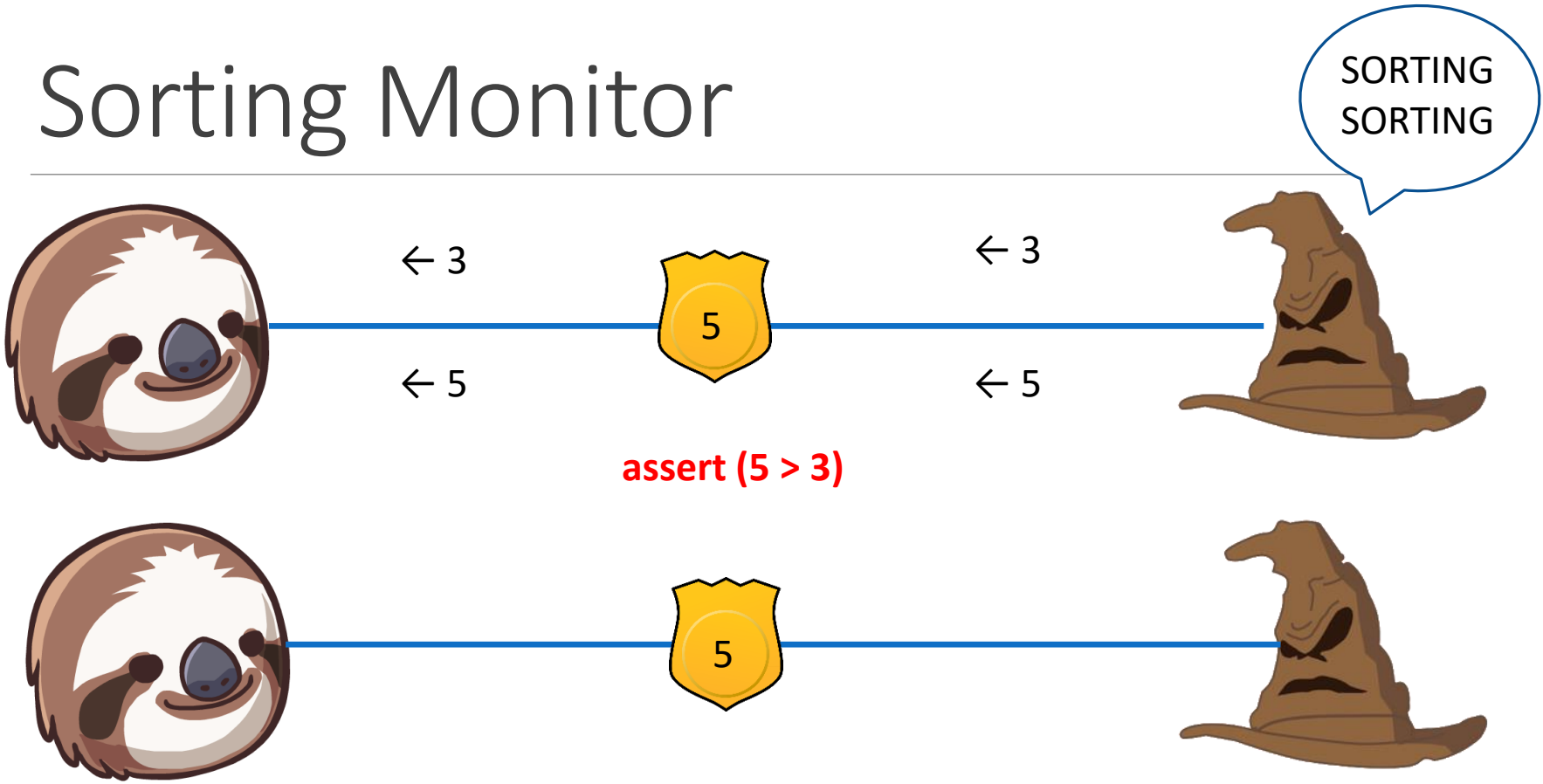

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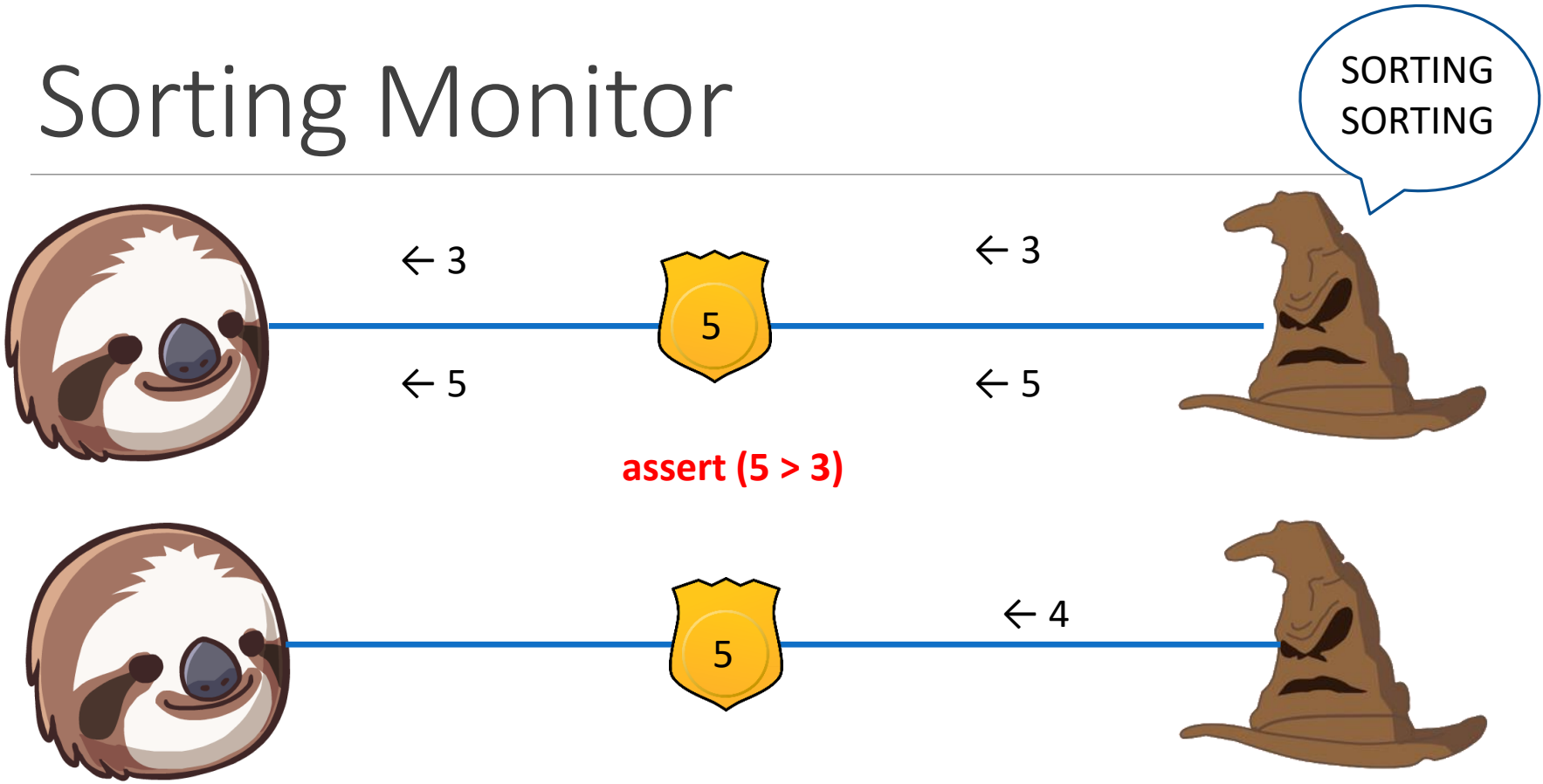

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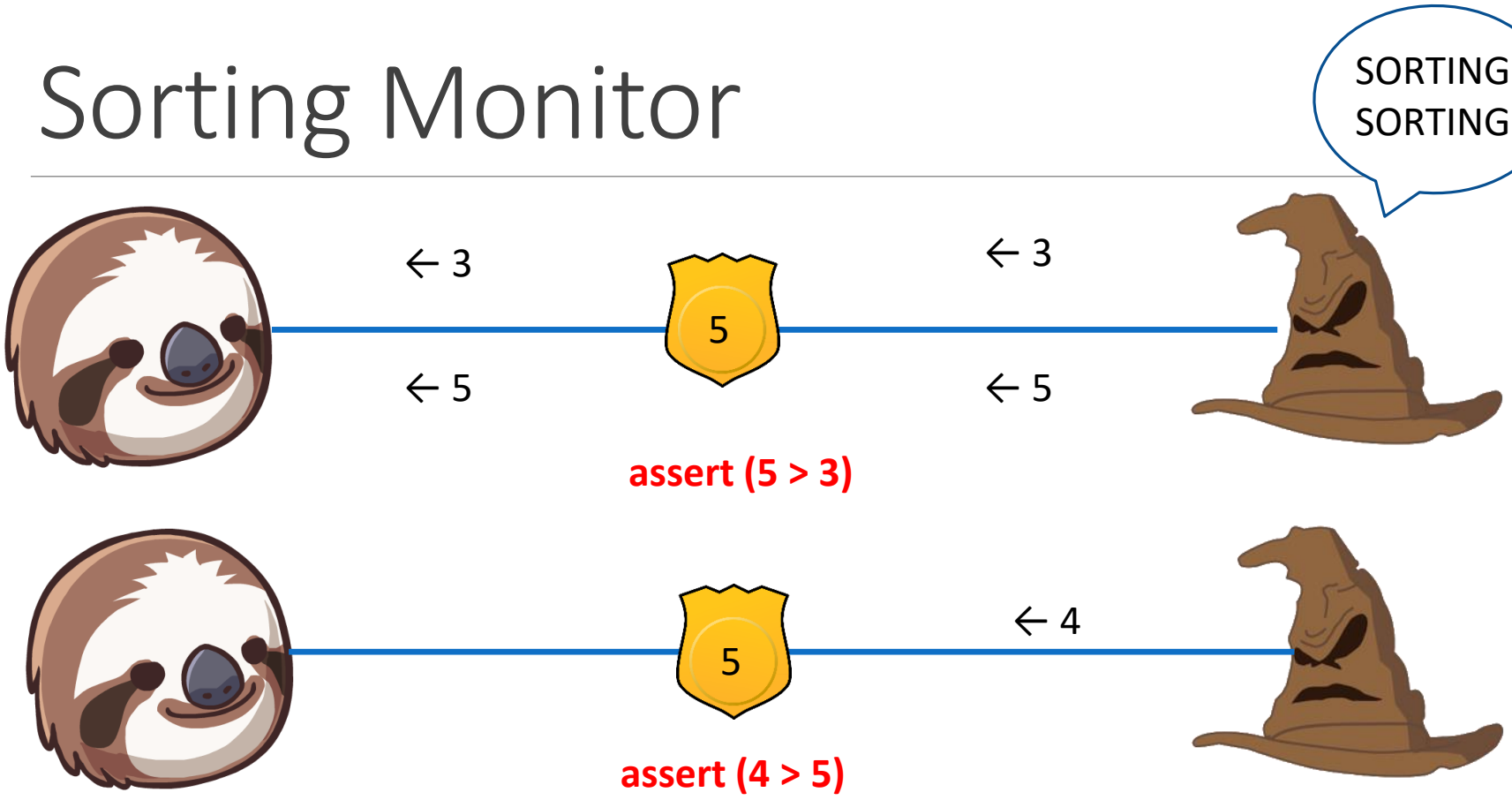

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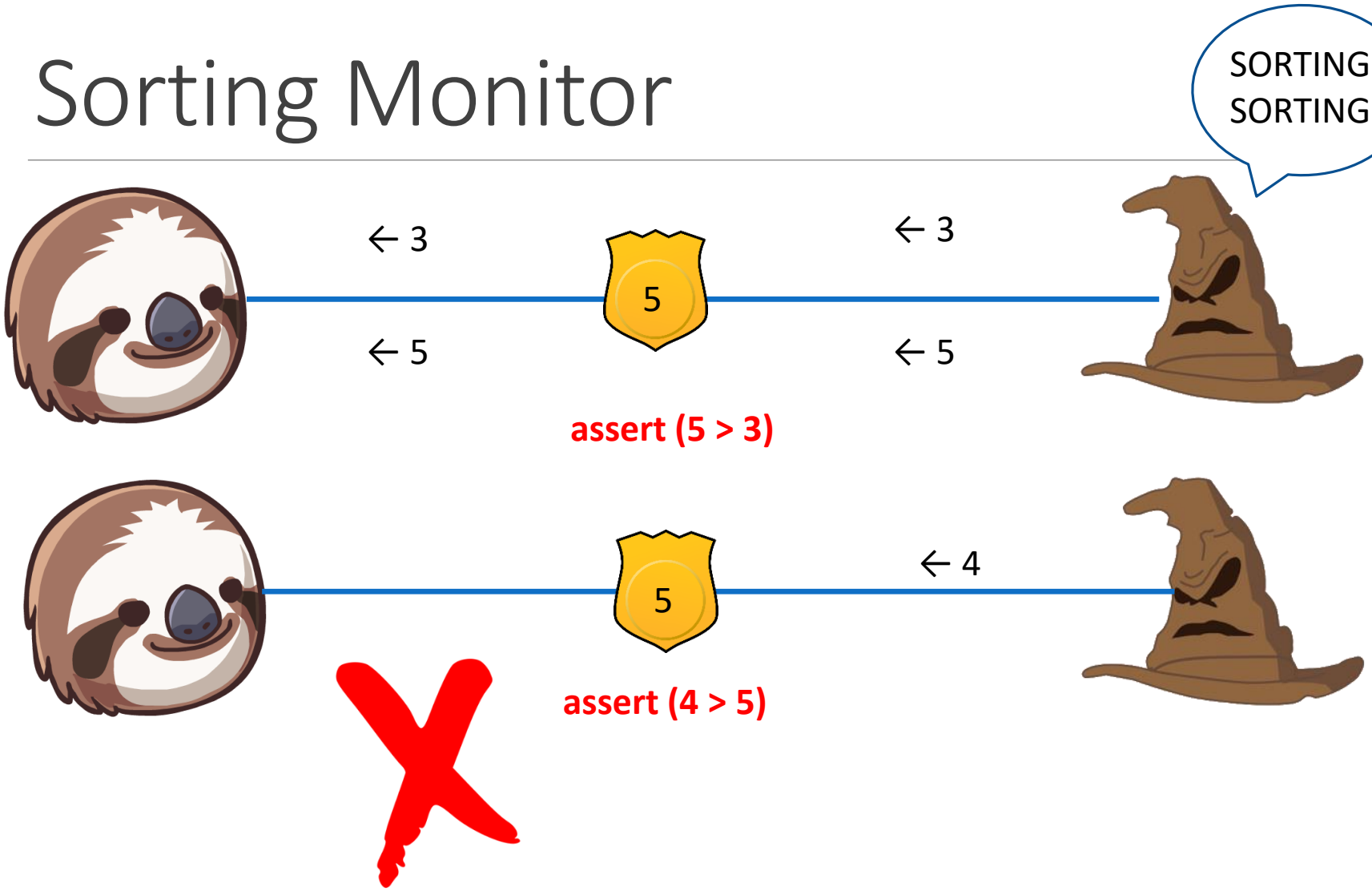


List Identity Process

list_id : list ← list

a ← list_id b =

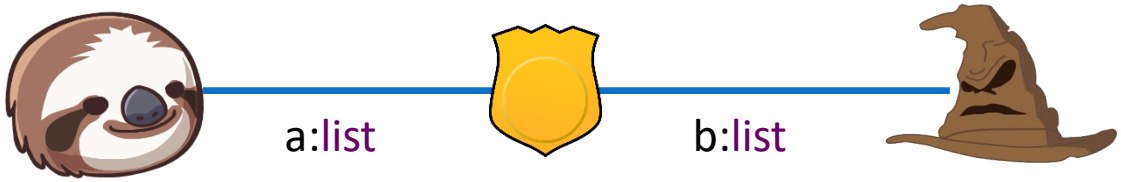
    case b of

        | nil ⇒ a.nil; wait b; close a

        | cons ⇒ x ← recv b;

                 a.cons(x);

                 a ← list_id b;



$$list = \oplus \{cons: int \wedge list; nil: 1\}$$

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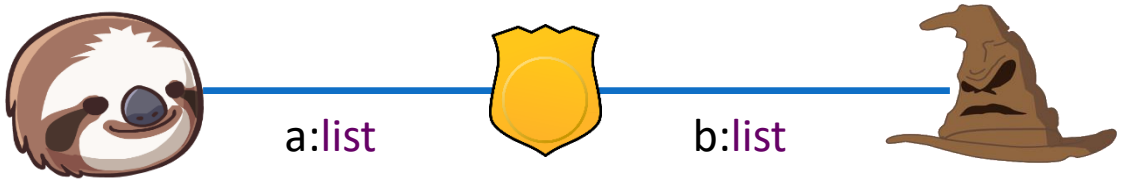

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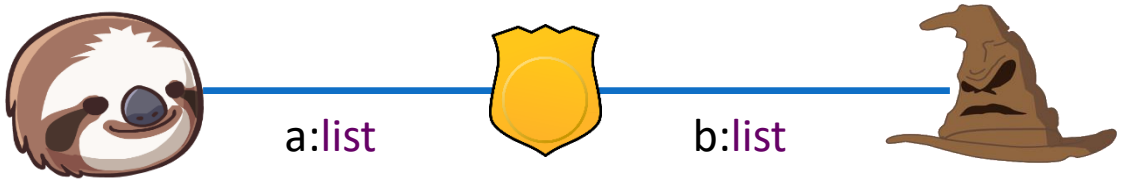

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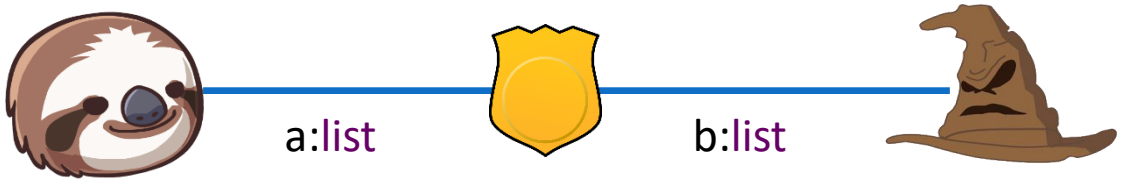

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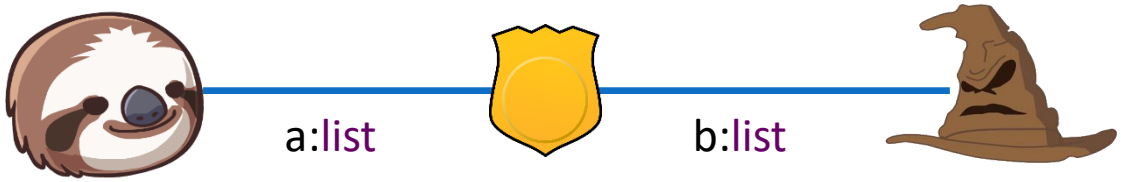
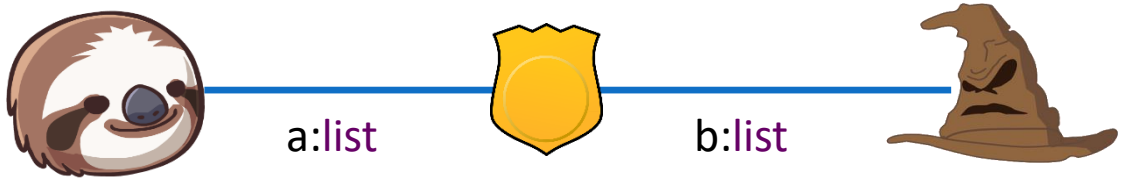


$$\mathit{list} = \oplus\{\mathit{cons}: \mathit{int} \wedge \mathit{list}; \mathit{nil}: \mathbf{1}\}$$

Sorted List

```
asc_mon: list ← int option, list ;;
a ← asc_mon bound b =
    case b of
      | nil ⇒ a.nil; wait b; close a
      | cons ⇒ x ← recv b;
```



$$list = \oplus\{cons: int \wedge list; nil: 1\}$$

```
        case bound of
         | None  ⇒ a.cons(x);  a ← asc_mon (Some x)  b
         | Some y ⇒ assert (x >= y);
                    a.cons(x); a ← asc_mon (Some x)  b;
```

Other Exciting Contracts

Contract	Monitor State
List of parentheses is well matched	Stack – push for (, pop for)
List of integers corresponds to correctly serialized binary tree	Stack – push for node, pop for leaf
Sorting procedure permutes elements of a list	Sum of hash values of each element
Doubling process mapped over a list of integers is monotonic	Input integer
Refinements on integers	None
Factoring procedures outputs integers that multiply to input	Input integer

Checking Refinements

- Encode refinements as type casts
- Can generate a partial identity monitor to check the refinement

$$\{A\}_a \Leftarrow \{B\}_b$$

Integer Refinement Translation

$$\{n\colon int \mid n > 0 \wedge A\}_a \Leftarrow \{n\colon int \wedge B\}_b$$

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x ← recv b;
send a x;

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Label Refinement Translation

$$\oplus\{\boldsymbol{cons}: \boldsymbol{int} \wedge \boldsymbol{list}\}_{\boldsymbol{a}} \Leftarrow \oplus\{\boldsymbol{cons}: \boldsymbol{int} \wedge \boldsymbol{list}; \boldsymbol{nil}: \mathbf{1}\}_{\boldsymbol{b}}$$

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```
case b of
| nil =>
| cons =>
```

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case b of
| nil => assert (false)
| cons => a.cons;
```

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case b of
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```

$$\{\boldsymbol{int} \wedge \boldsymbol{list}\}_{\boldsymbol{a}} \Leftarrow \{\boldsymbol{int} \wedge \boldsymbol{list}\}_{\boldsymbol{b}}$$

Translation is Transparent

- Prove that generated monitors are partial identity processes

$$\mathrm{a}:\mathrm{A} \leftarrow \mathrm{b}:\mathrm{B}$$

$$\approx$$

$$\mathrm{a} \leftarrow \boxed{\{\boldsymbol{A}\}_{\boldsymbol{a}} \Leftarrow \{\boldsymbol{B}\}_{\boldsymbol{b}}} \leftarrow \mathrm{b}$$

Redundant Monitor

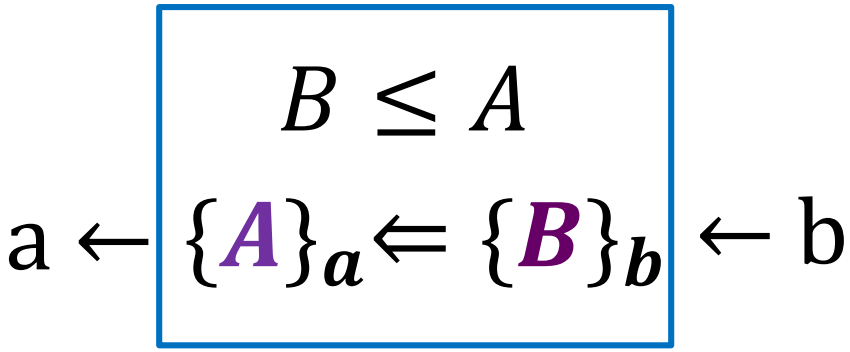
$$\oplus\{\boldsymbol{cons}: \boldsymbol{int} \wedge \boldsymbol{list}; \boldsymbol{nil}: \mathbf{1}\}_{\boldsymbol{a}} \Leftarrow \oplus\{\boldsymbol{cons}: \boldsymbol{int} \wedge \boldsymbol{list}\}_{\boldsymbol{b}}$$

```
case b of
| cons => a.cons;
```

$$\{\boldsymbol{int} \wedge \boldsymbol{list}\}_{\boldsymbol{a}} \Leftarrow \{\boldsymbol{int} \wedge \boldsymbol{list}\}_{\boldsymbol{b}}$$

Safety Theorem

- Prove that subtype casts do not cause assertion failures



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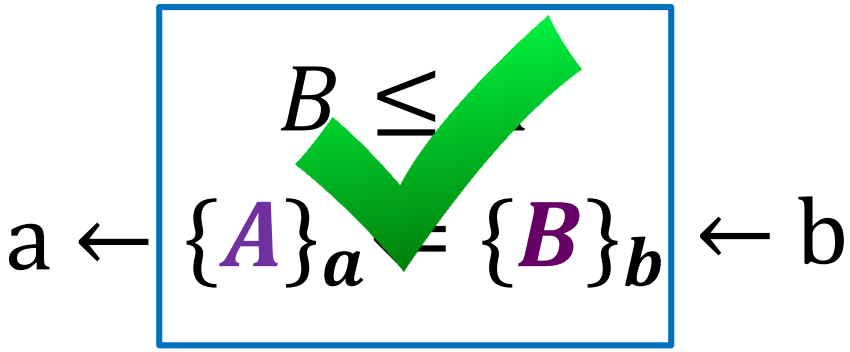
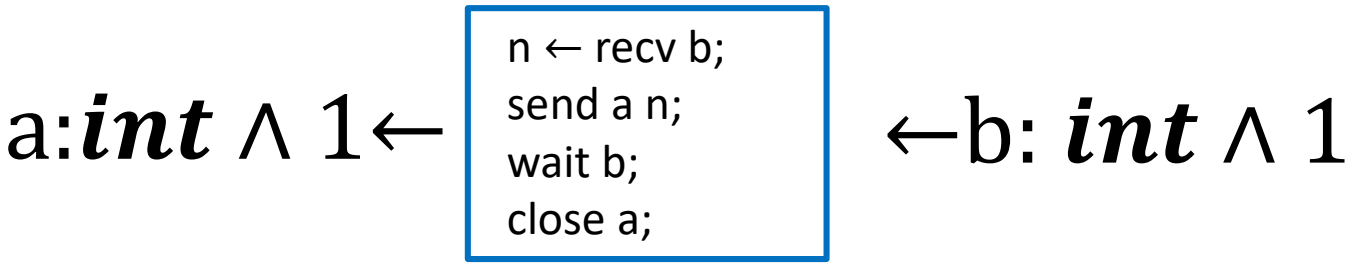


Partial Identity Rules



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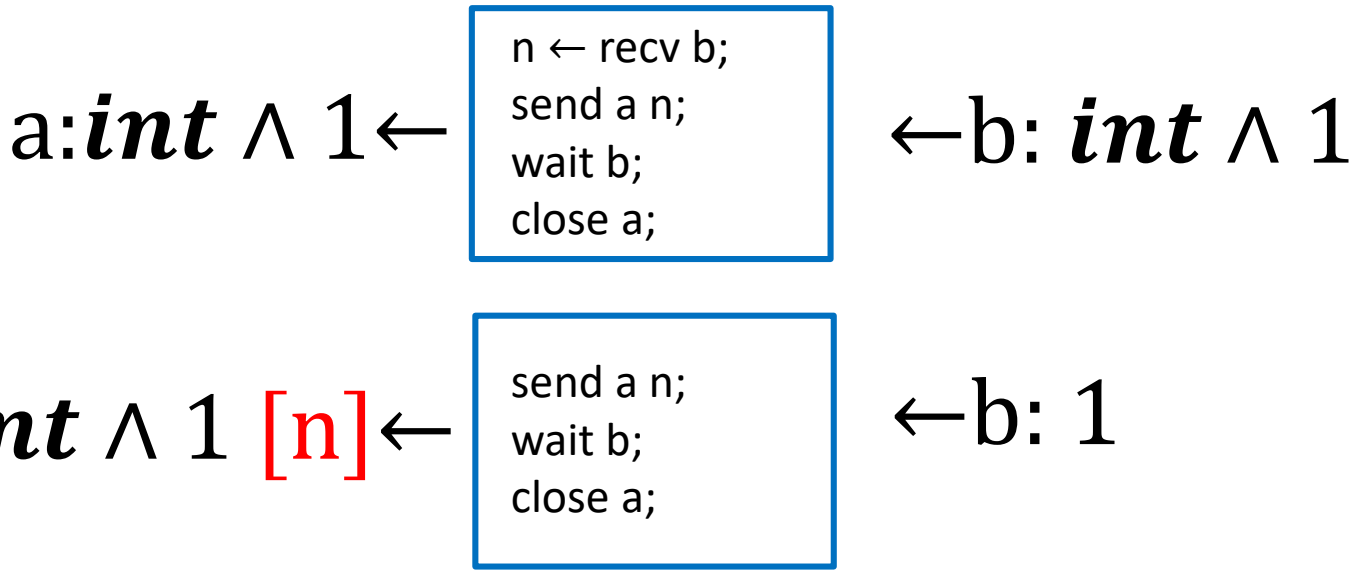

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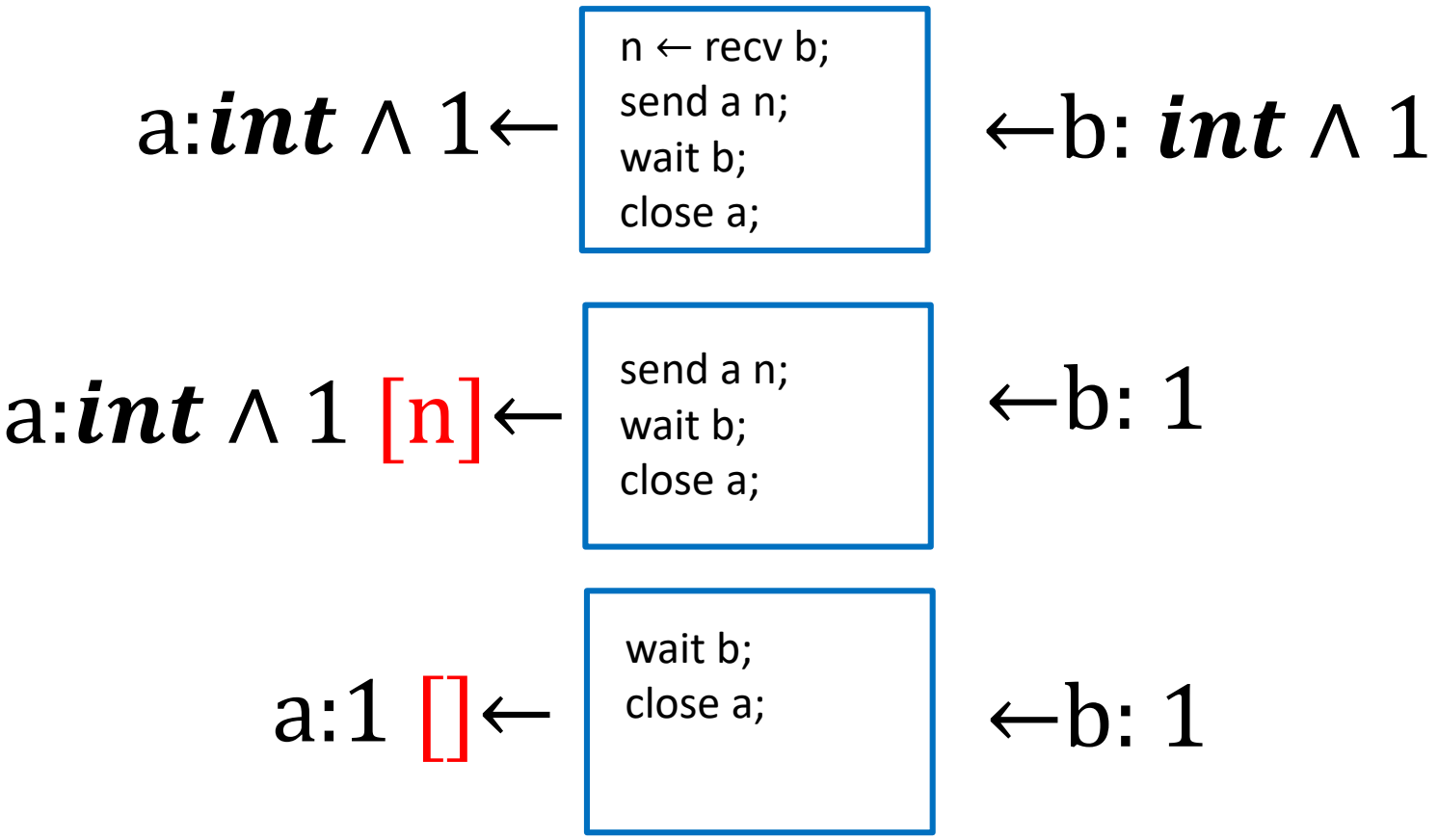

Partial Identity Criterion

- Complications occur when monitors spawn other monitors (higher order case)
- Construct a bisimulation between monitoring processes and identity processes showing that every observable message is the same

Future Work

- Even more exciting contracts!
  - Contracts which require distributed state (ghost messages), ie permutation checking
  - Noninterference/information flow contracts

Related Work

- Recently:
  - Melgratti & Padovani (ICFP 2017)
  - Waye et al (ICFP 2017)
- Contracts: Findler & Felleisen (2002), Dimoulas et al (2011,2012), Disney et al (2012)

Takeaway

Partial identity monitors provide a mechanism to express complex stateful contracts in the same language as the target code