Objects as Session-Typed Processes

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AGERE! 2015

The essence of object-orientation

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object, encapsulation, message passing, information hiding, dynamic dispatch, reuse, modularization, inheritance, etc.

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- Objects interact by message exchange (Smalltalk, Actor model)

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Object-orientation to Alan Kay [public email]:

“OOP to me means only messaging, local retention and protection and hiding of state-process, and extreme late-binding of all things. It can be done in Smalltalk and in LISP. There are possibly other systems in which this is possible, but I’m not aware of them.”

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- Objects encapsulate state
- Computation by message exchange
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Suggested model of computation:

- inherently concurrent
- allows expression of valid sequences of state transitions

This paper in a nutshell

A fresh look at object-oriented programming:

- Objects as processes
- Objects interact by sending messages along channels, where objects are identified with offering channel
- Channels (and offering object) are typed by linear session types, making client own the offering object

We introduce the programming language CLOO and show that:

- typical oo patterns (dynamic dispatch, subtyping) arise naturally
- new forms of expression (type-directed reuse, internal choice) emerge

Important concern:

- Support program reasoning, whilst maintaining object-oriented style

Contributions

Concurrent message-passing programming model with:

- static protocol assurance
- absence of data races and deadlocks

Object-oriented programming model with:

- typical oo concepts (encapsulation, dynamic dispatch, subtyping)
- new forms of expressions (type-directed reuse, internal choice)

Prototype compiler:

- Supports most of presented features

Progress and preservation proof (in meantime):

- for core subset of language

Outline

Background: linear session types

Basic correspondence between CLOO - object-oriented concepts:

- Objects as processes
- Dynamic dispatch
- Structural subtyping

New forms of expression:

- Type-directed delegation
- Internal Choice

Conclusions

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Linear session-based communication

[Based on intuitionistic linear sequent calculus]

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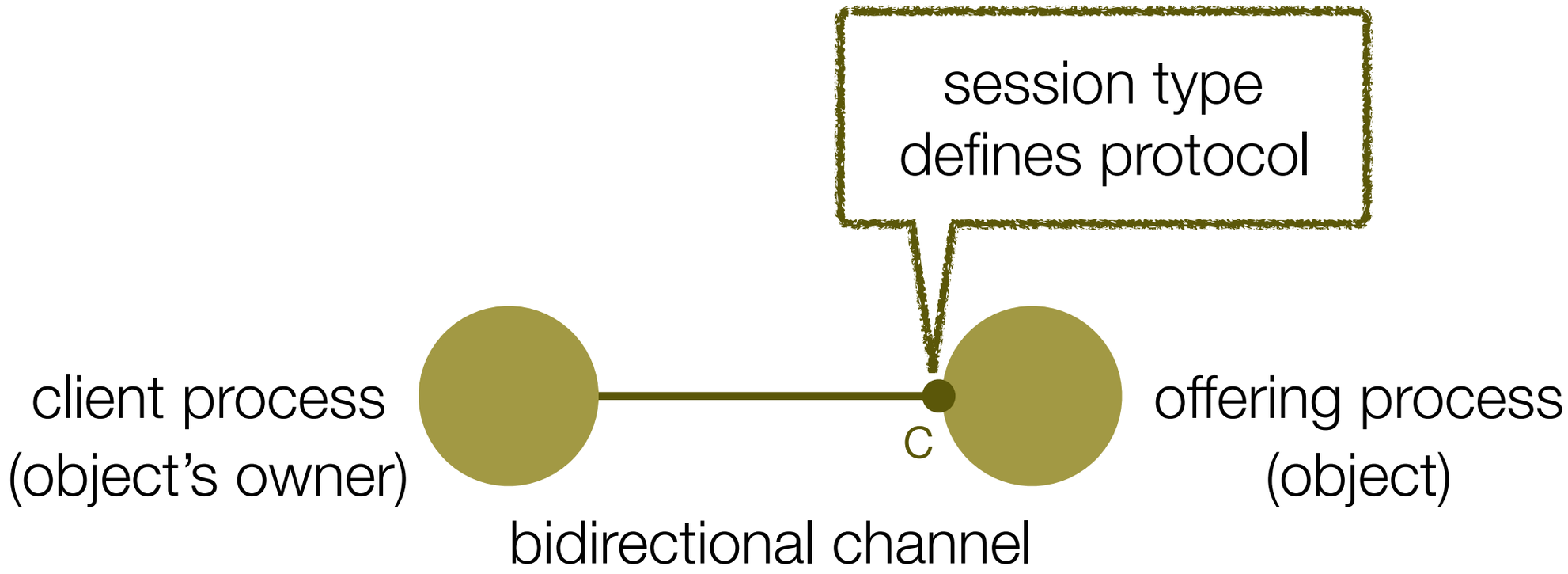

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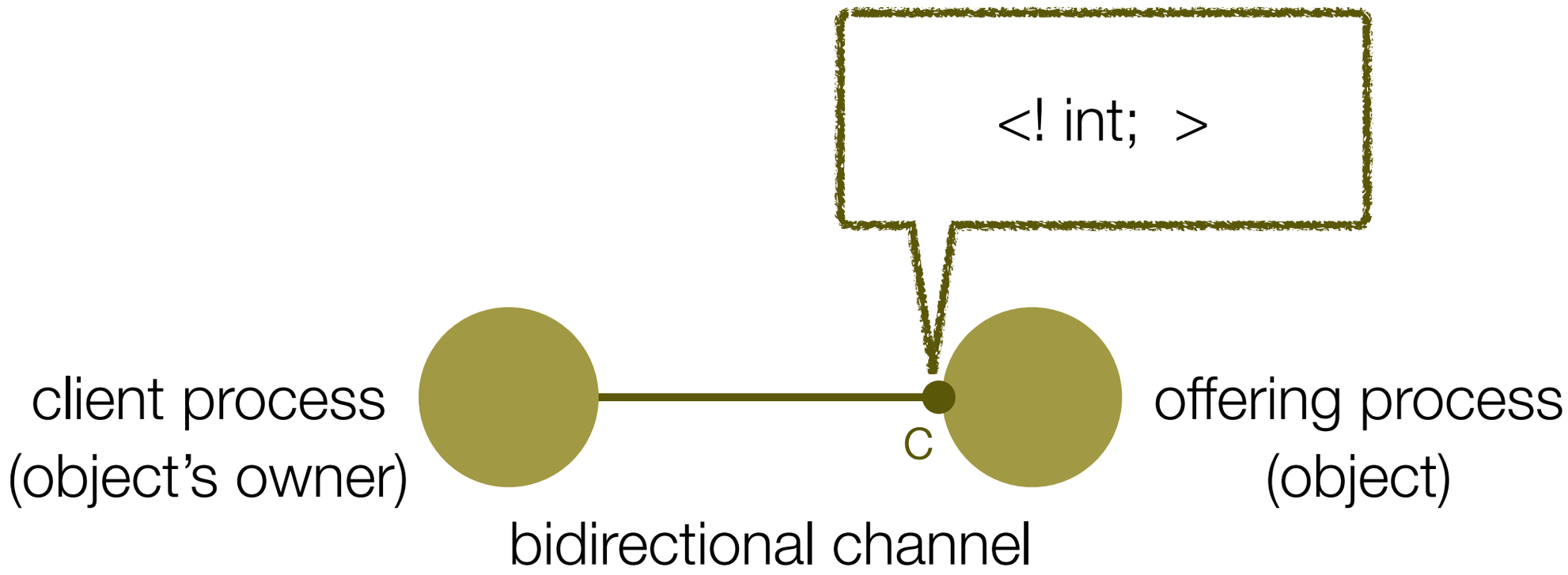

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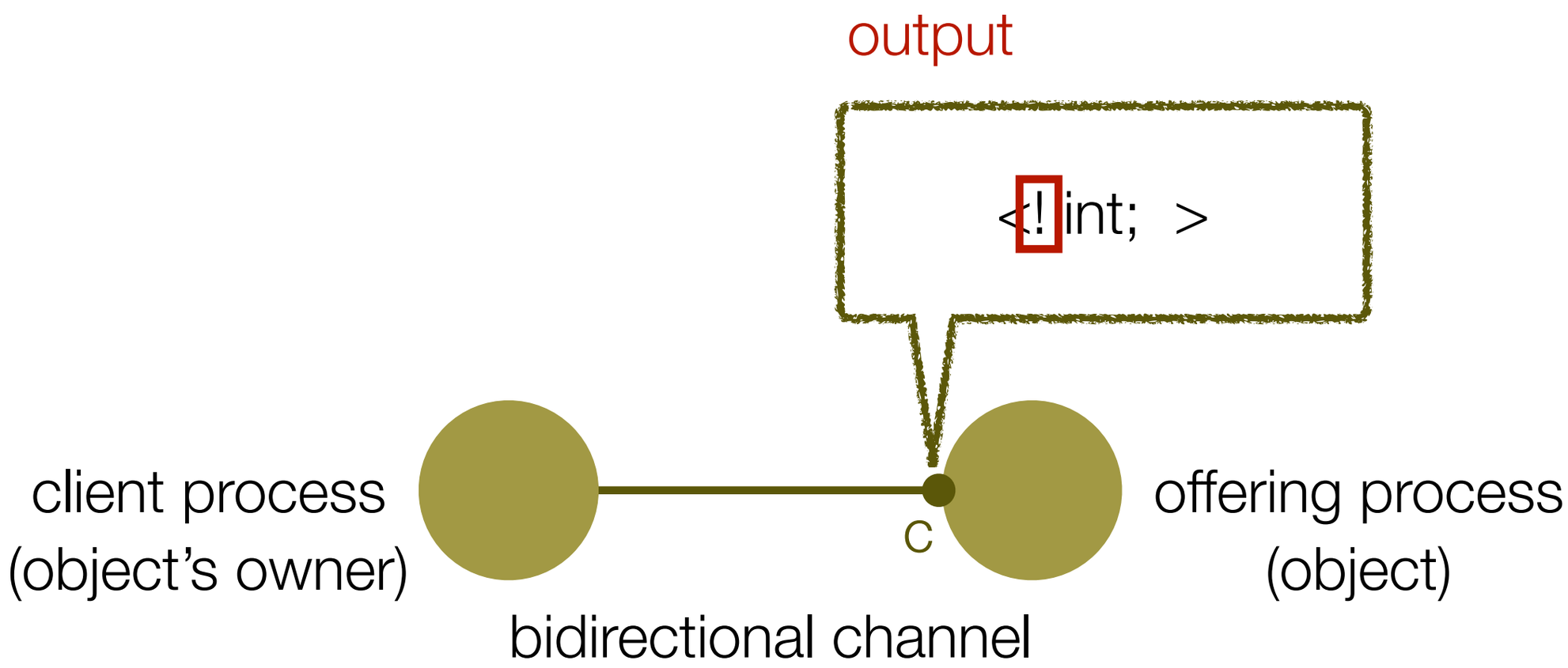

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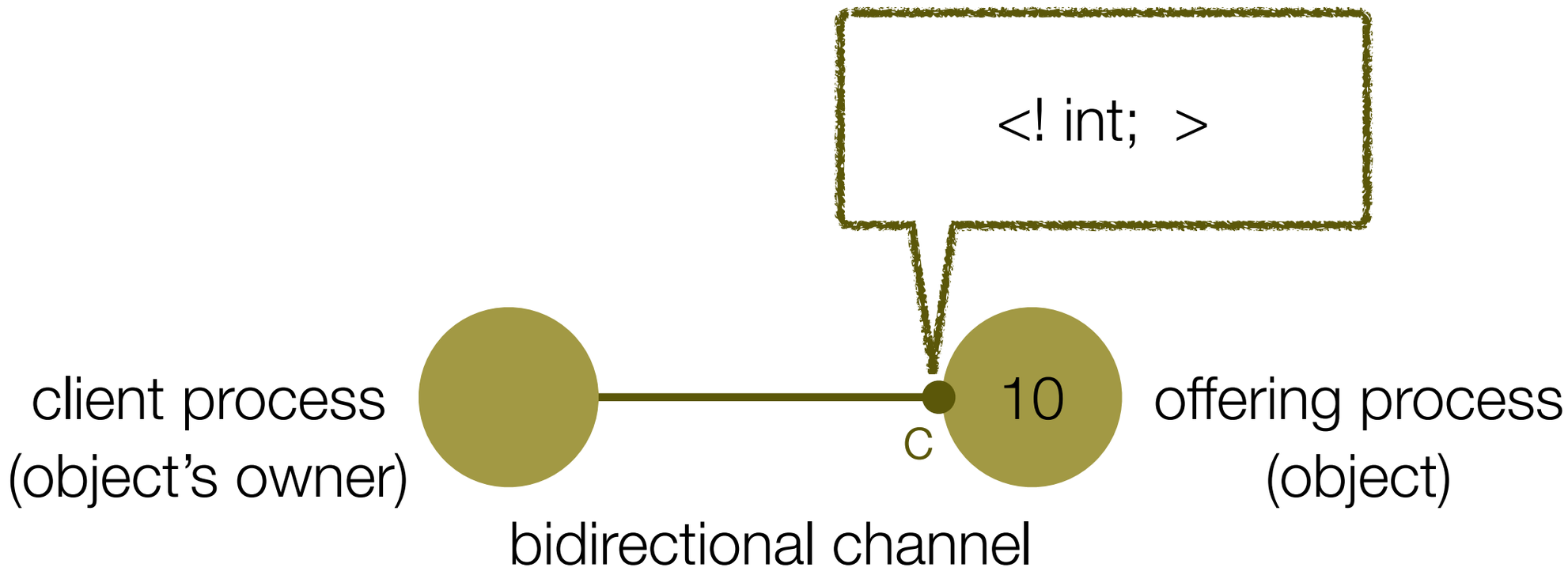

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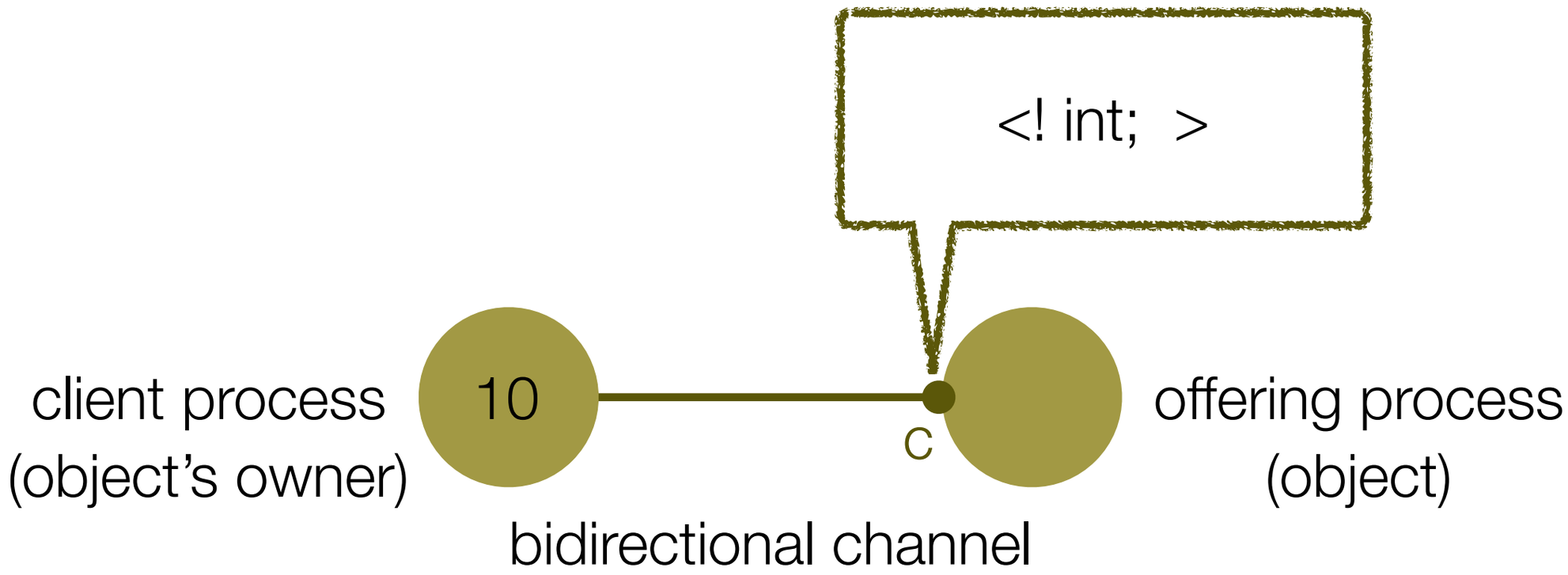

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client process
(object's owner)

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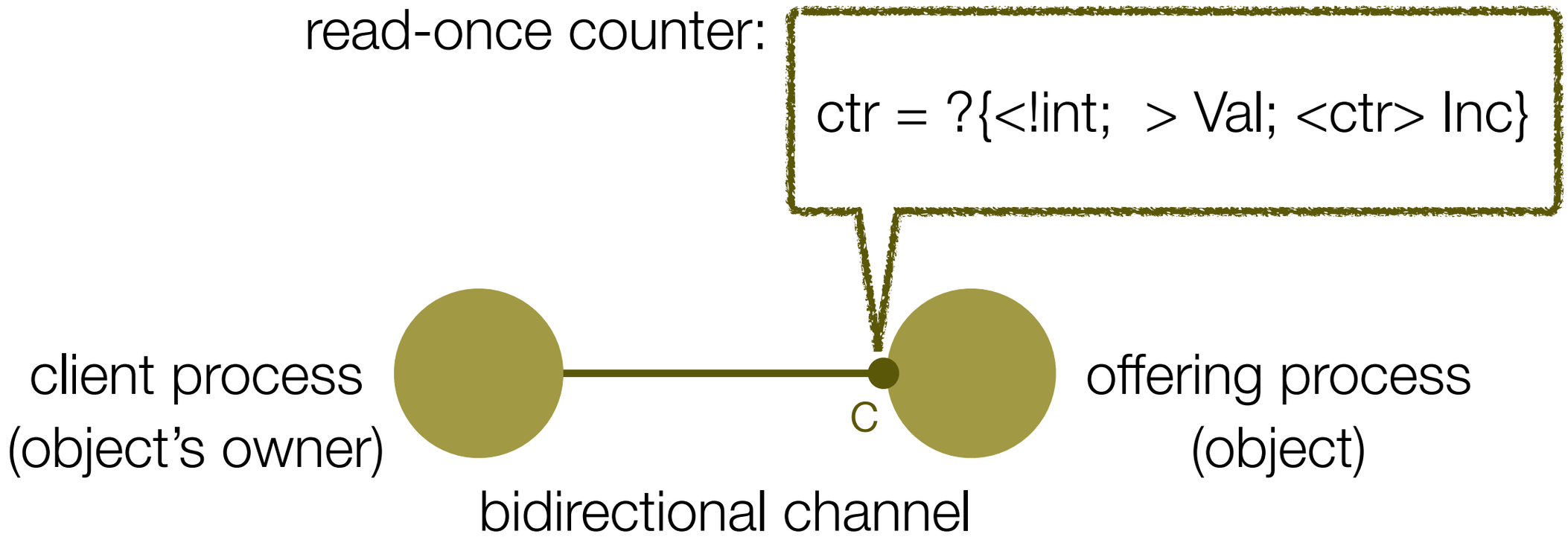

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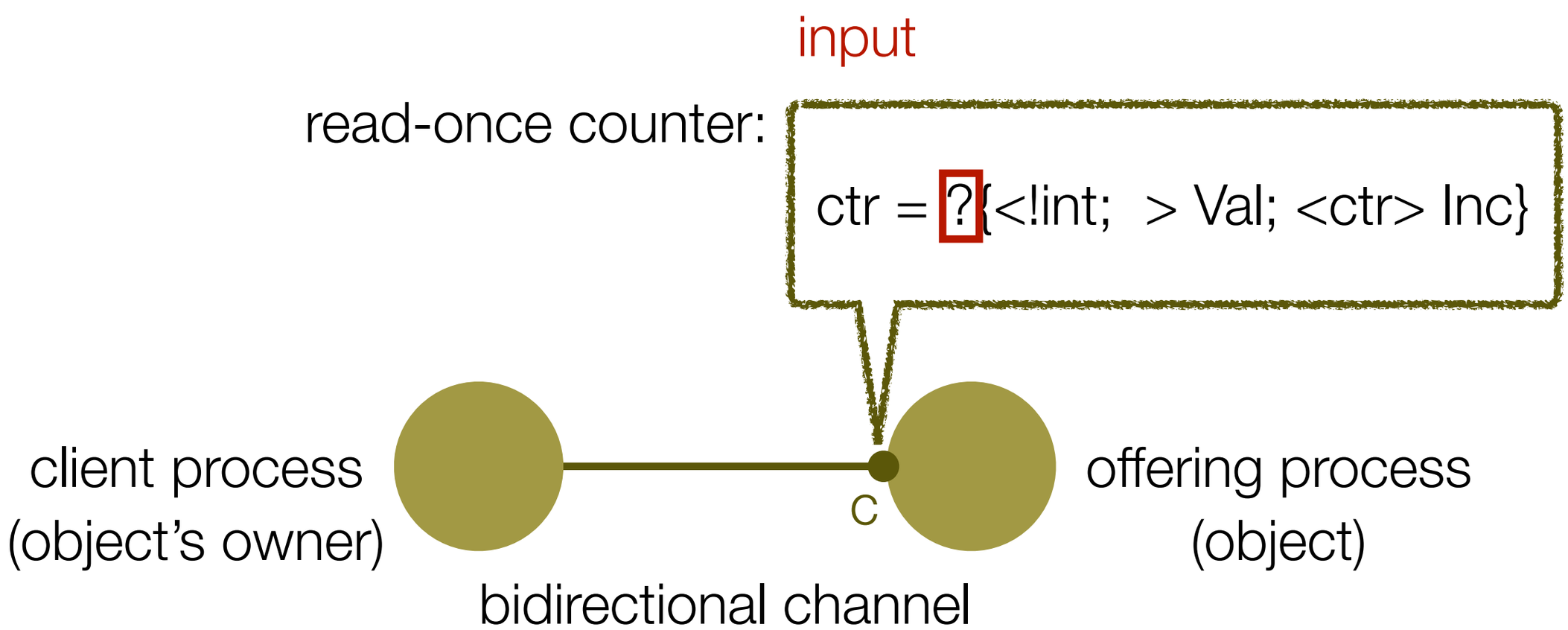

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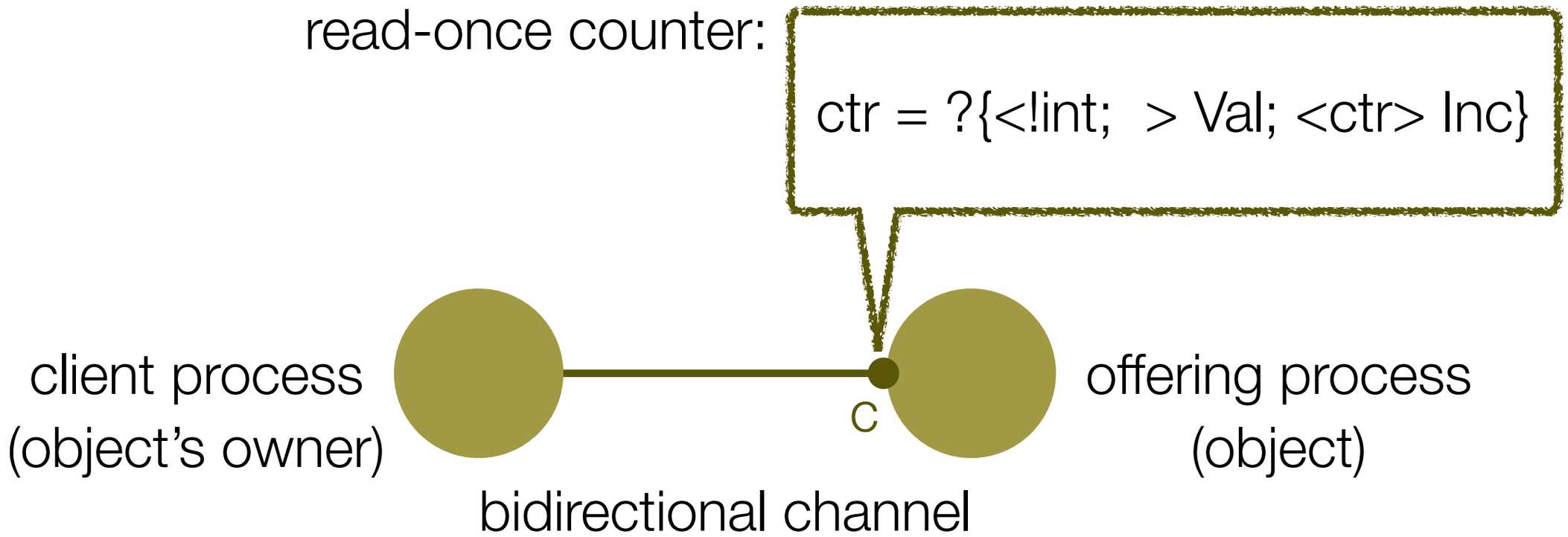

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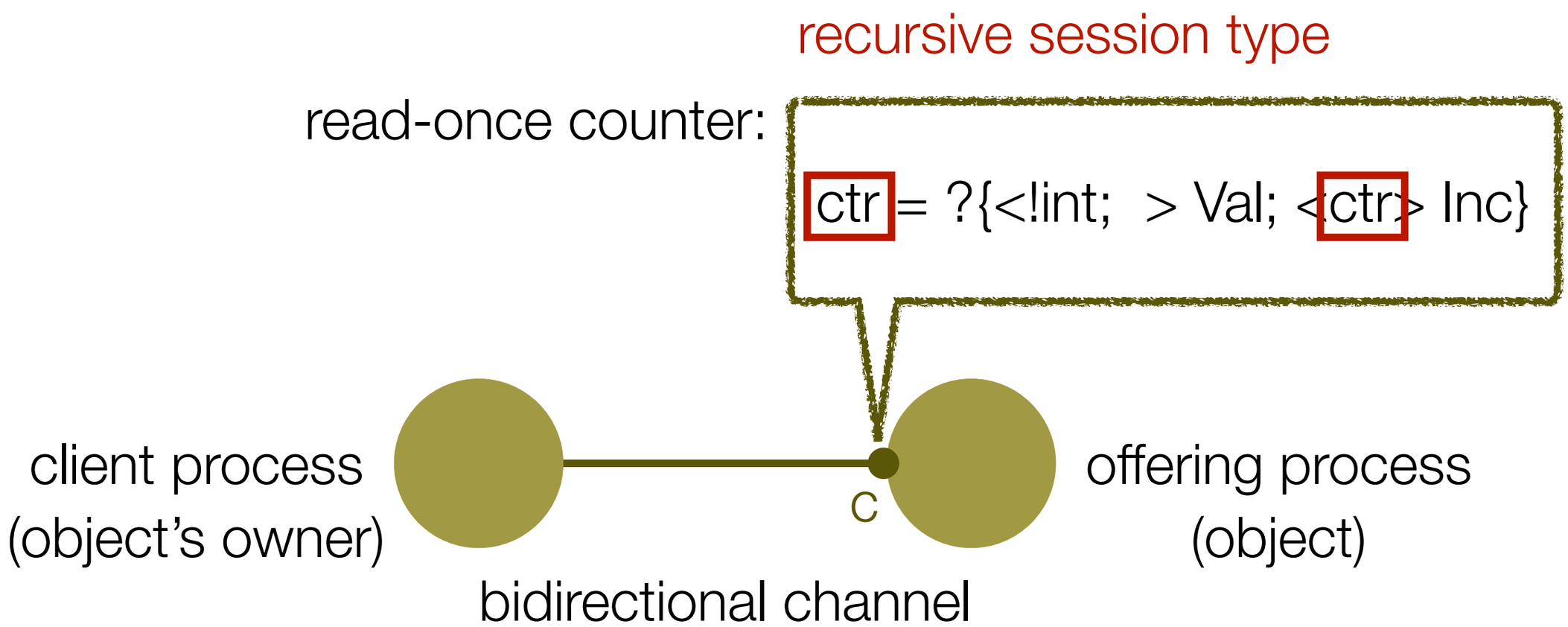

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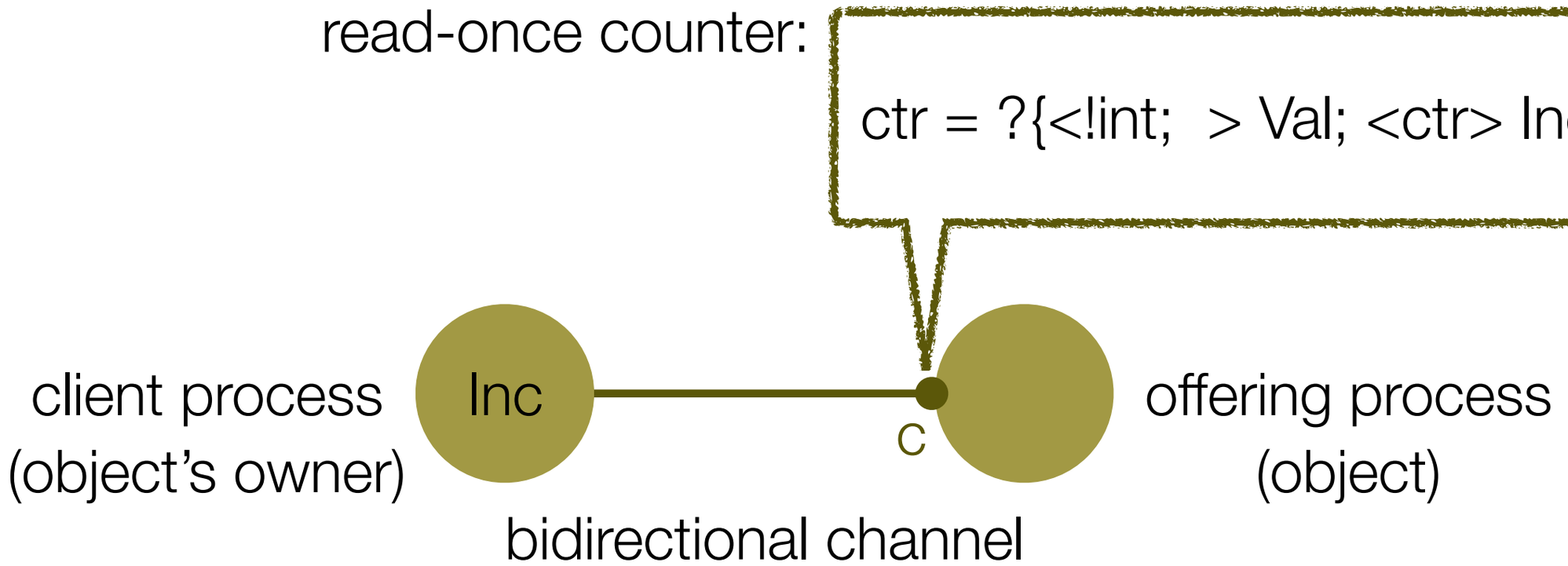

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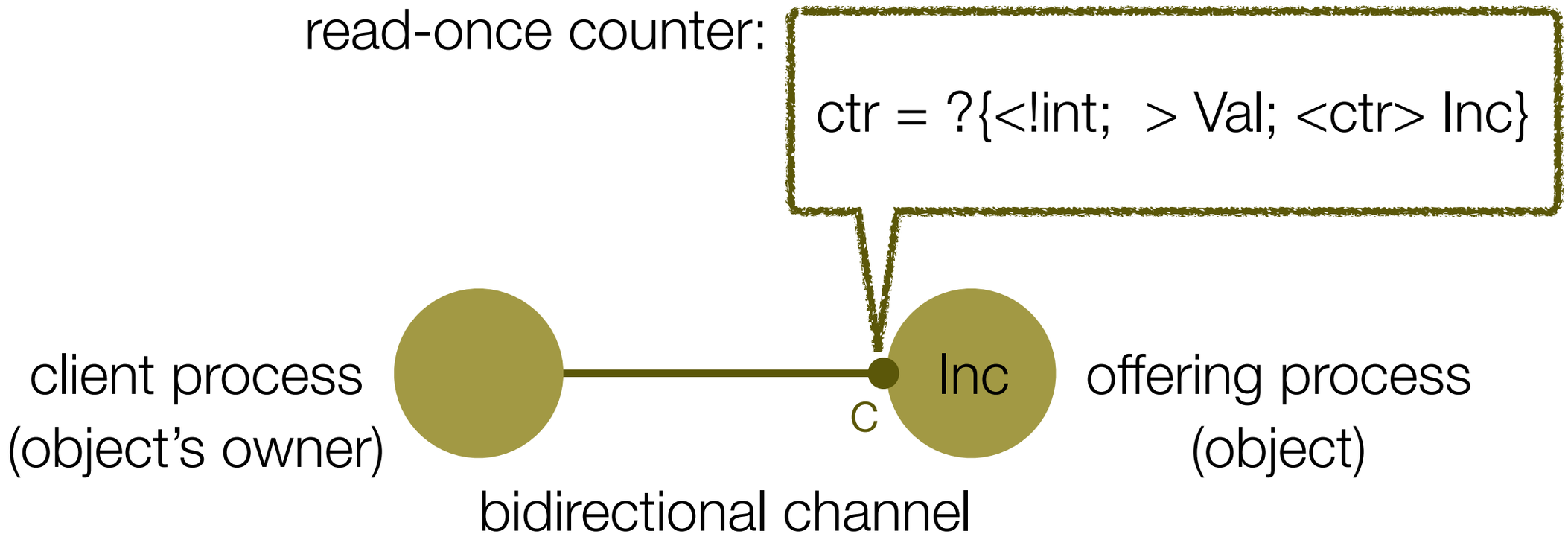

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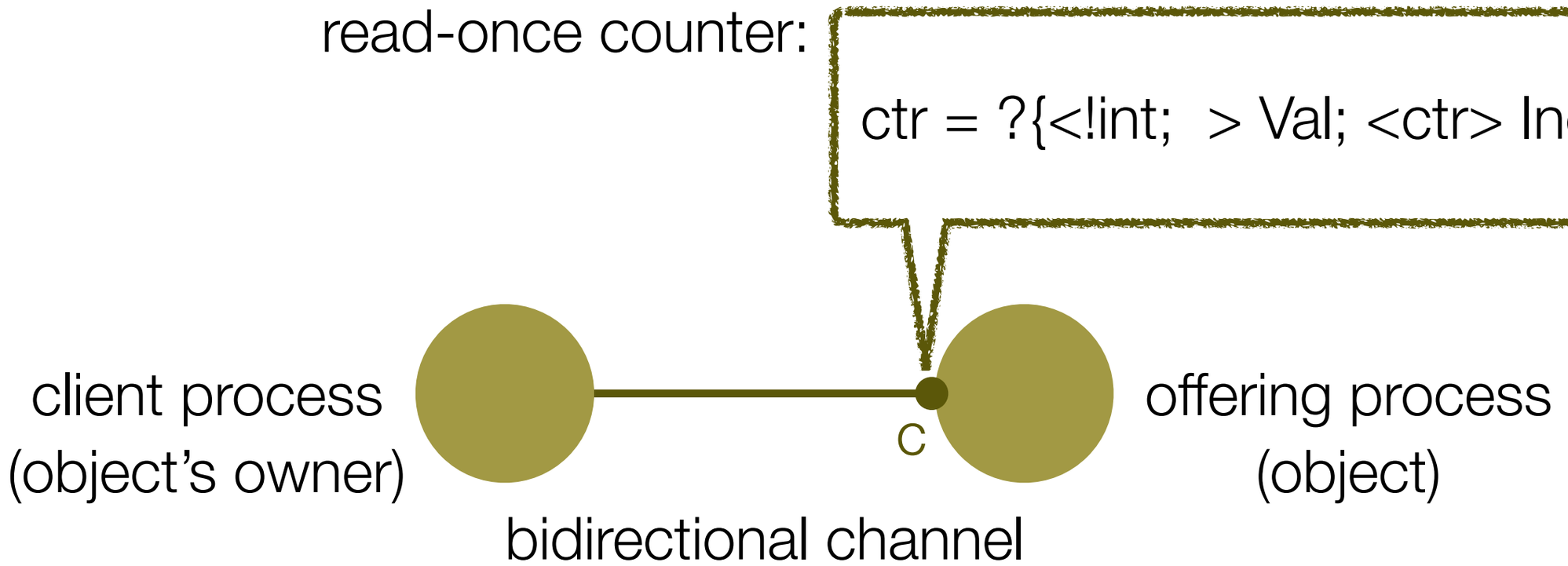

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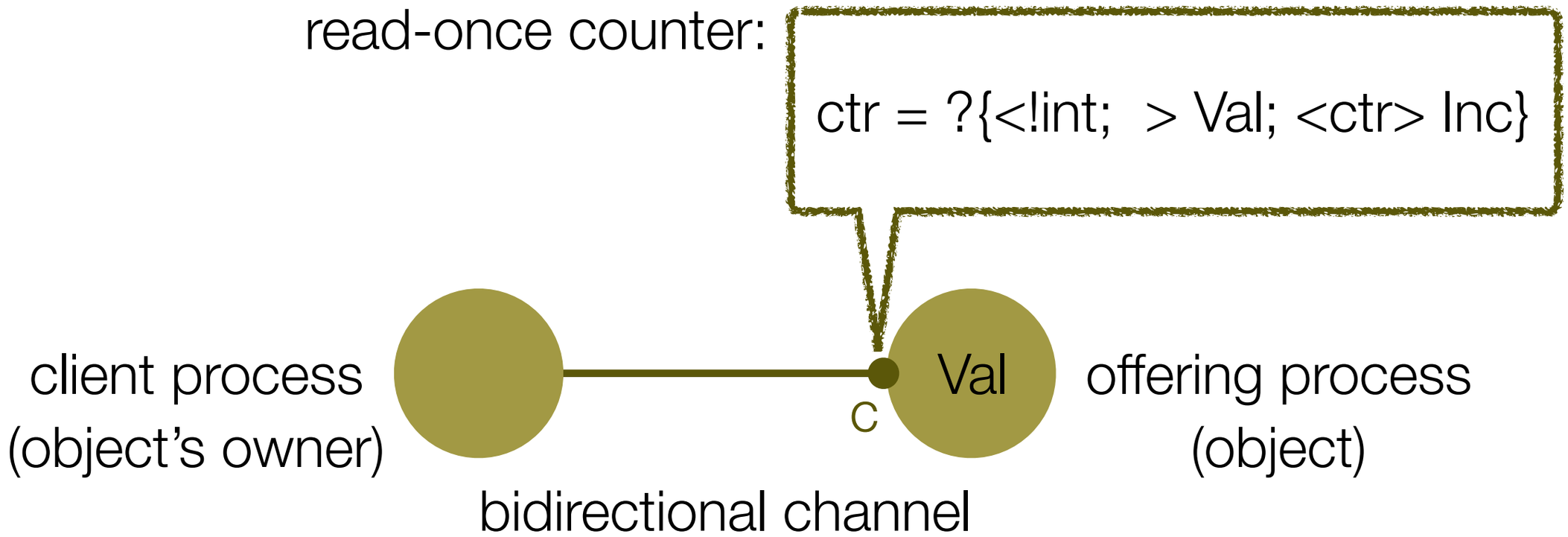

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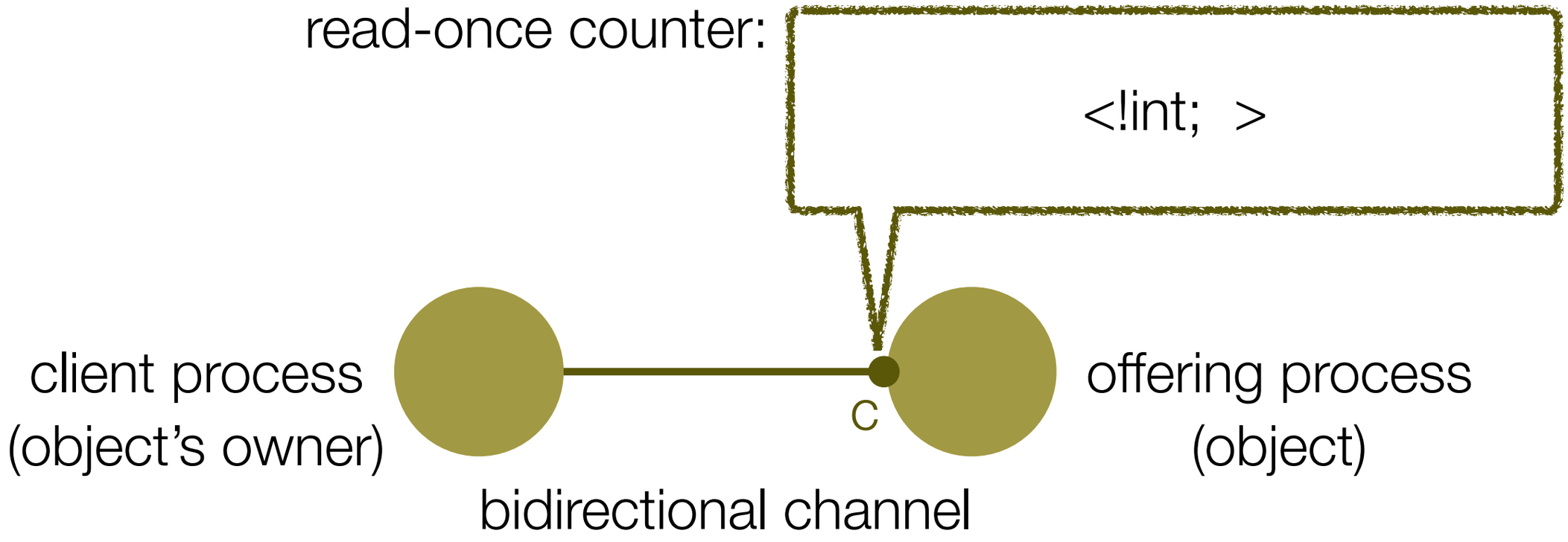

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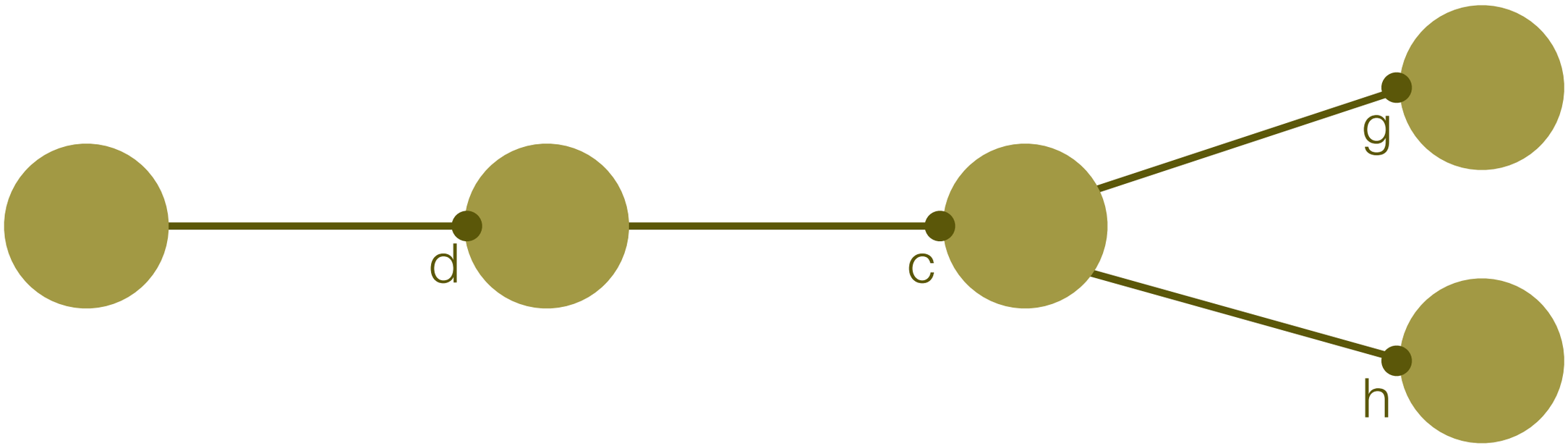

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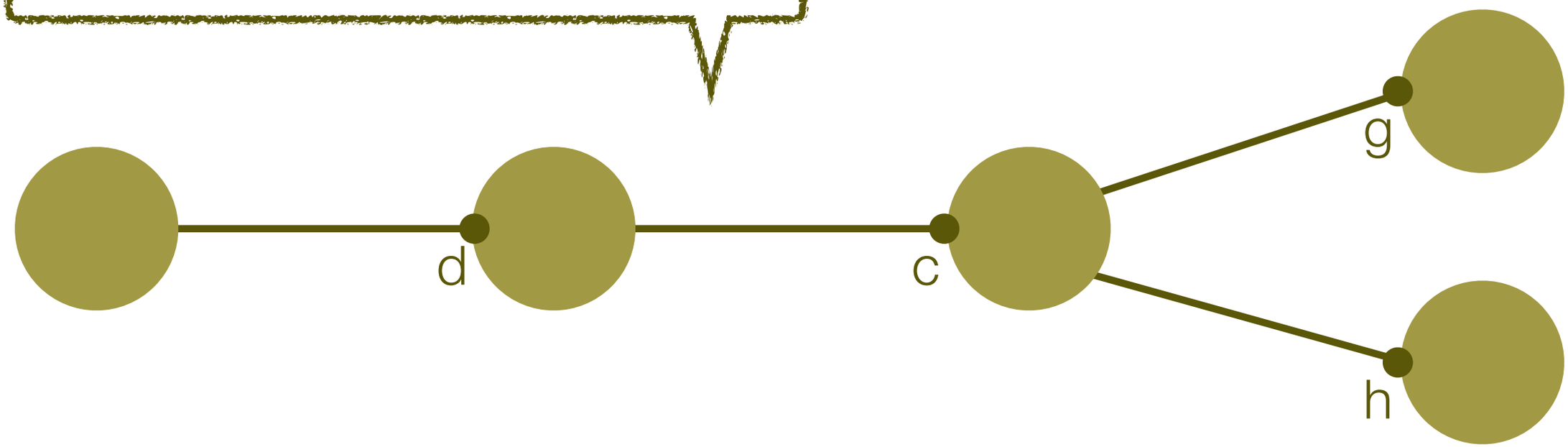
linearity: channels as resources



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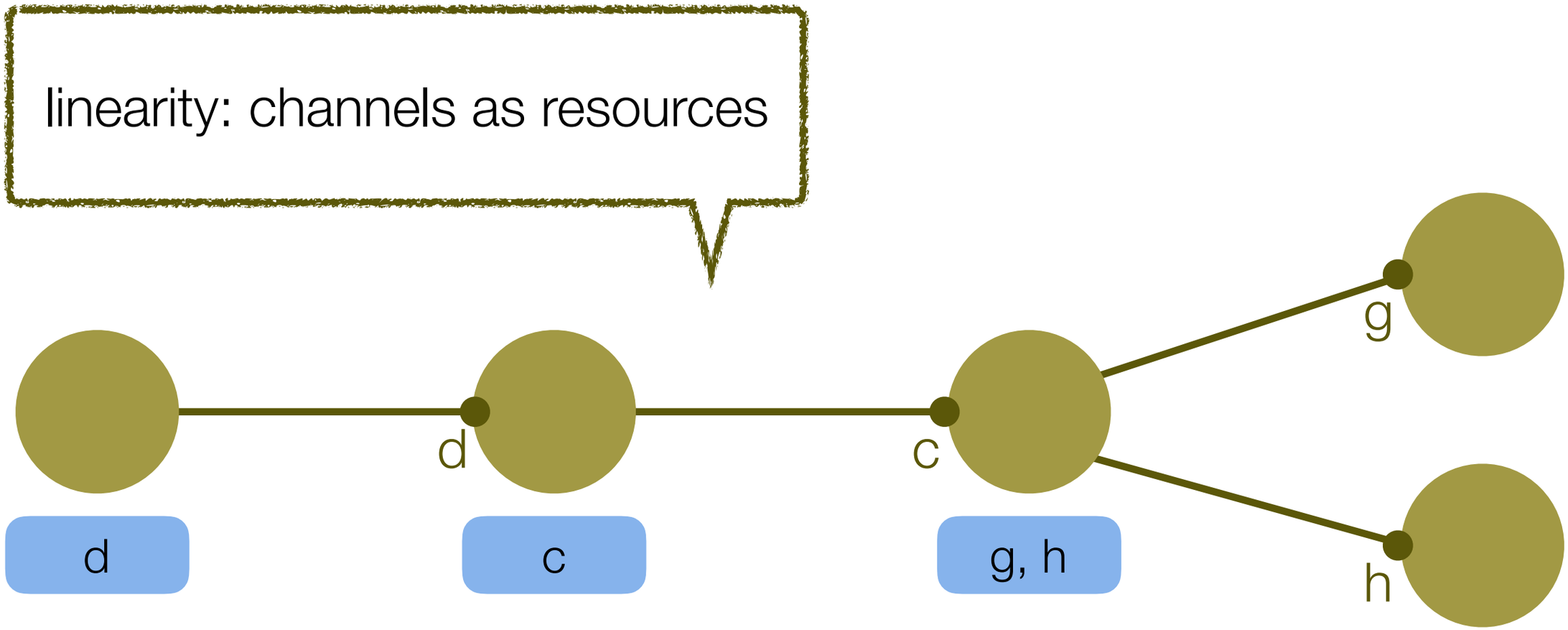

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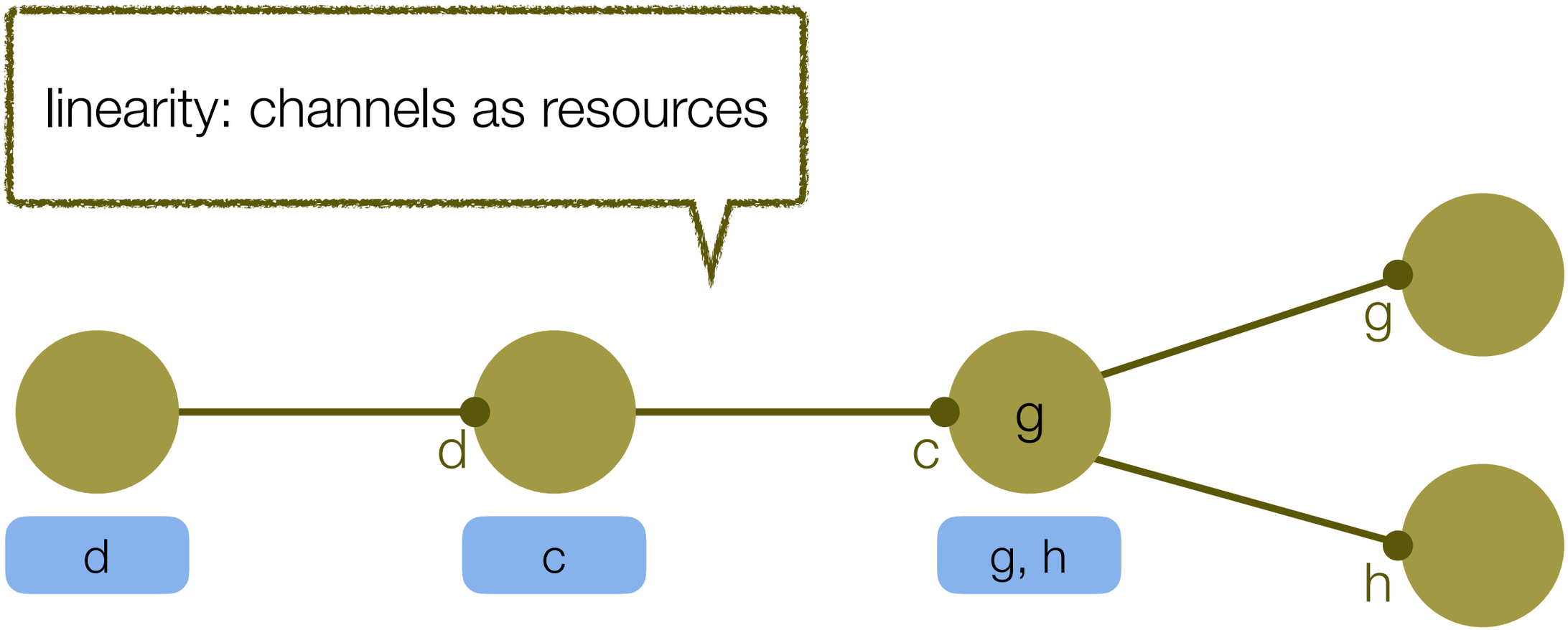

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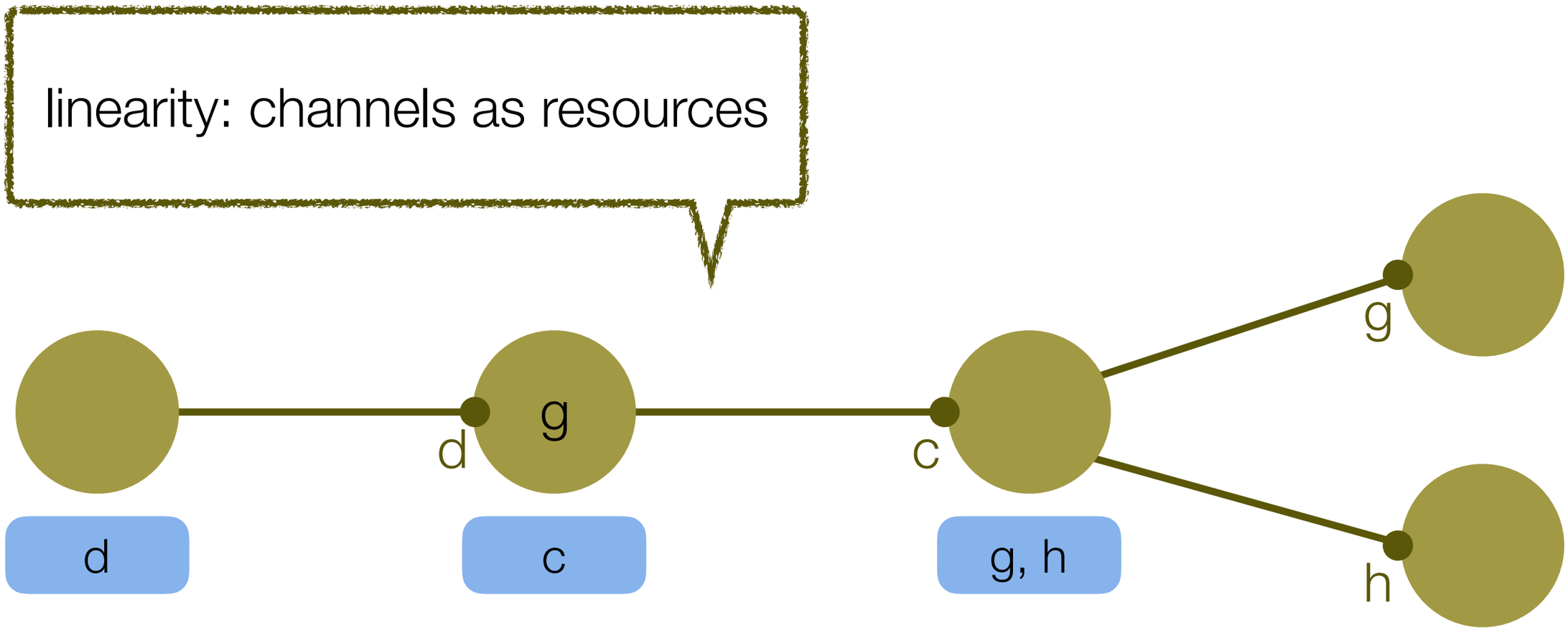

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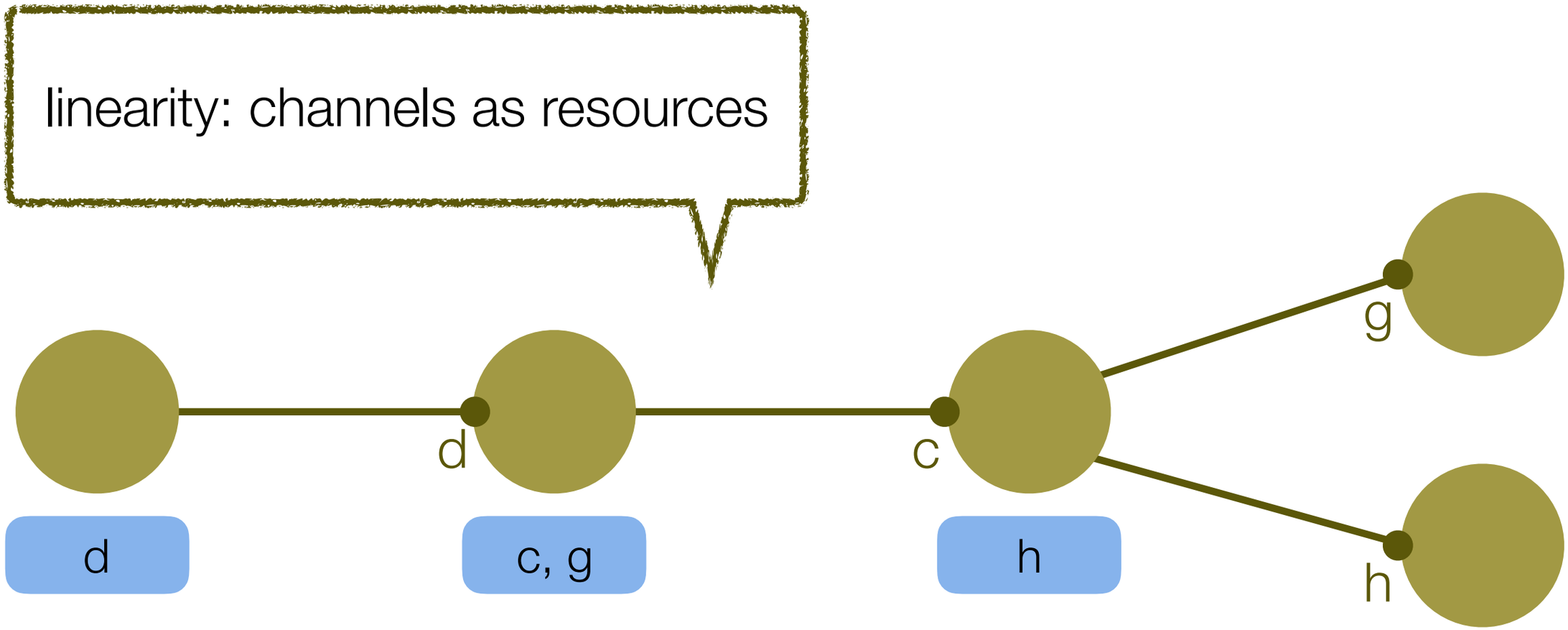

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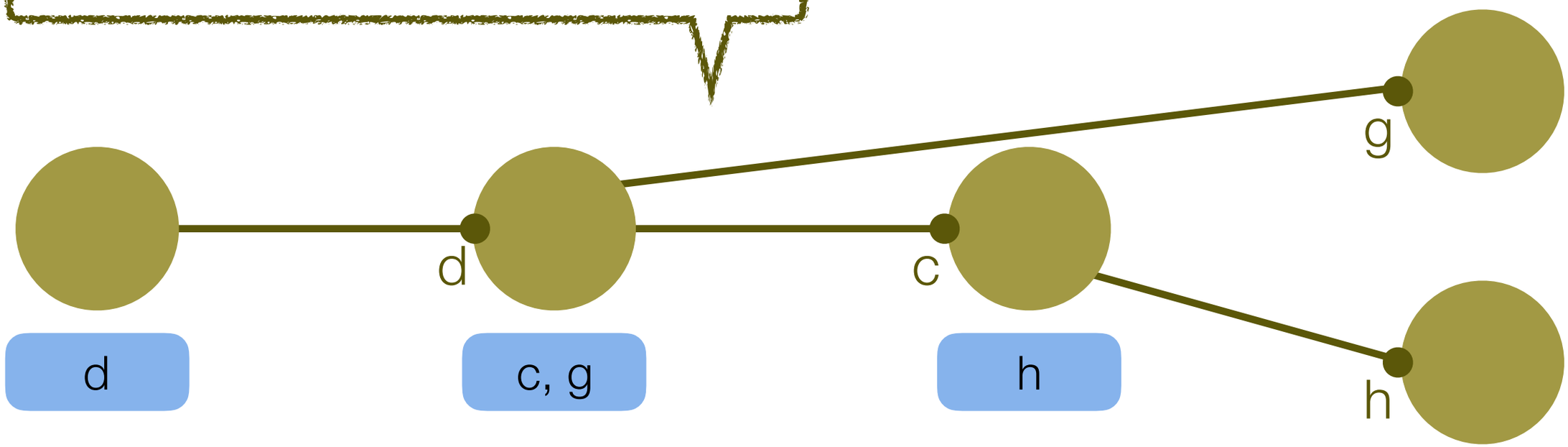

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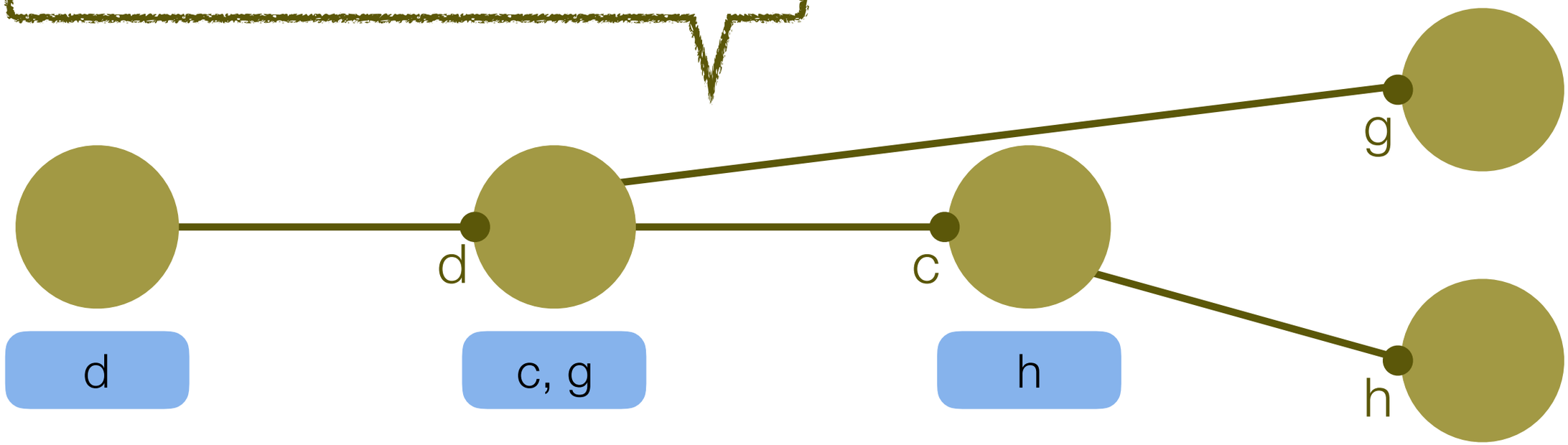

→ Processes form (dynamically changing) tree

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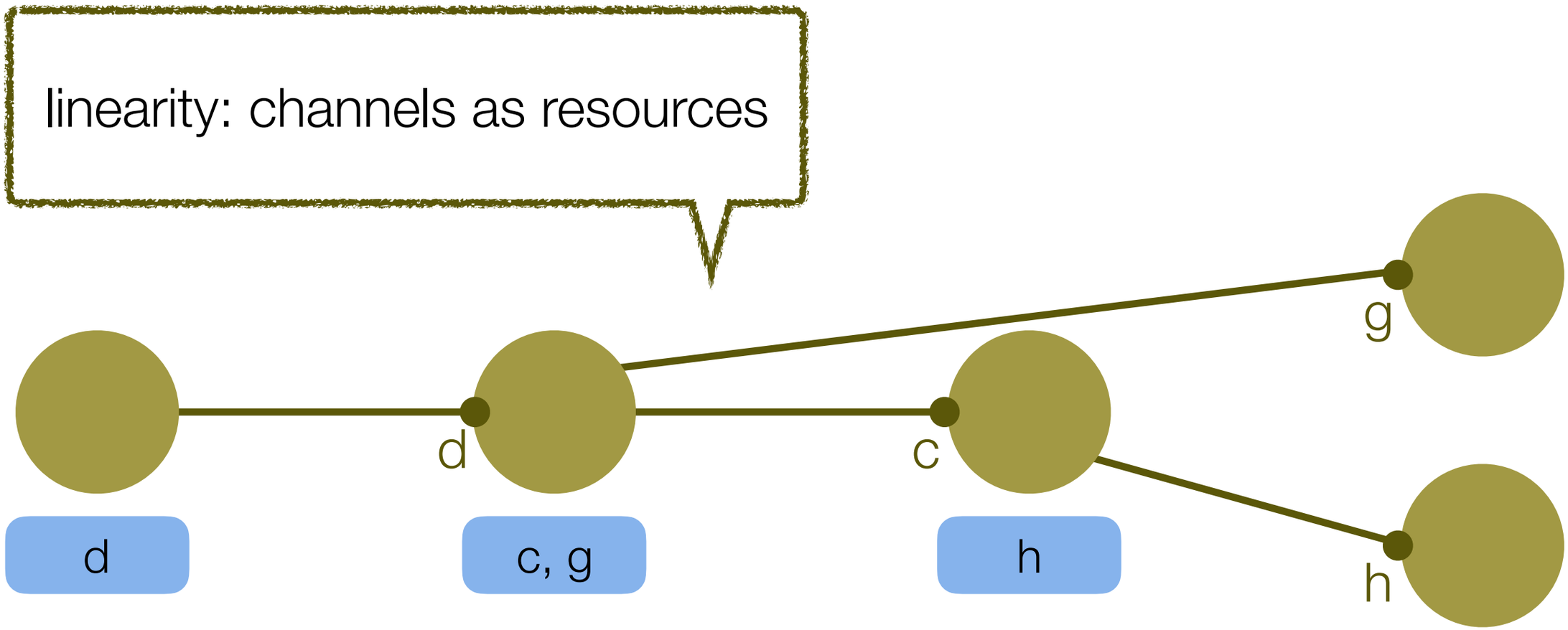

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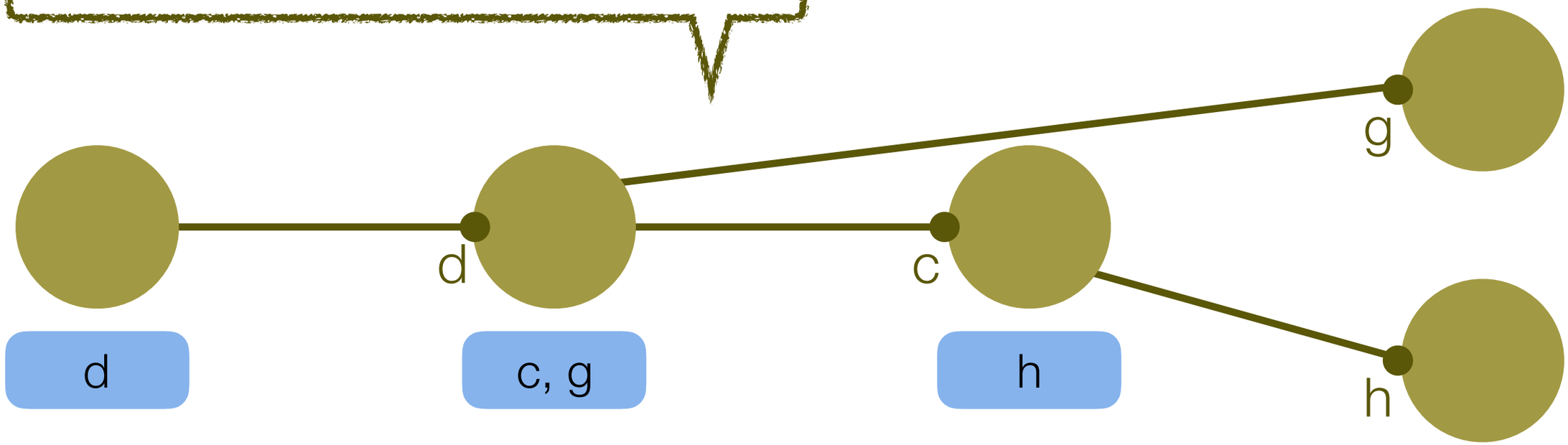

Linearity guarantees session fidelity and freedom from data races and deadlock

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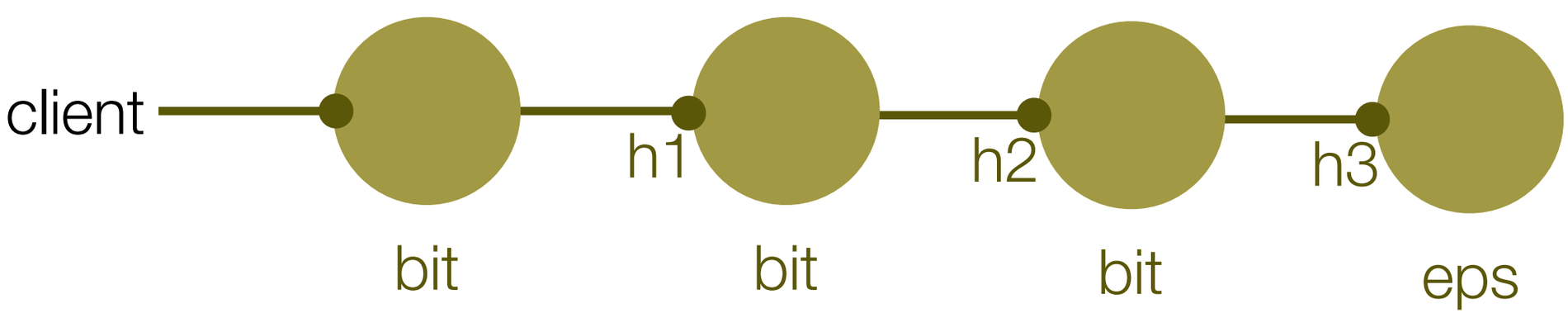

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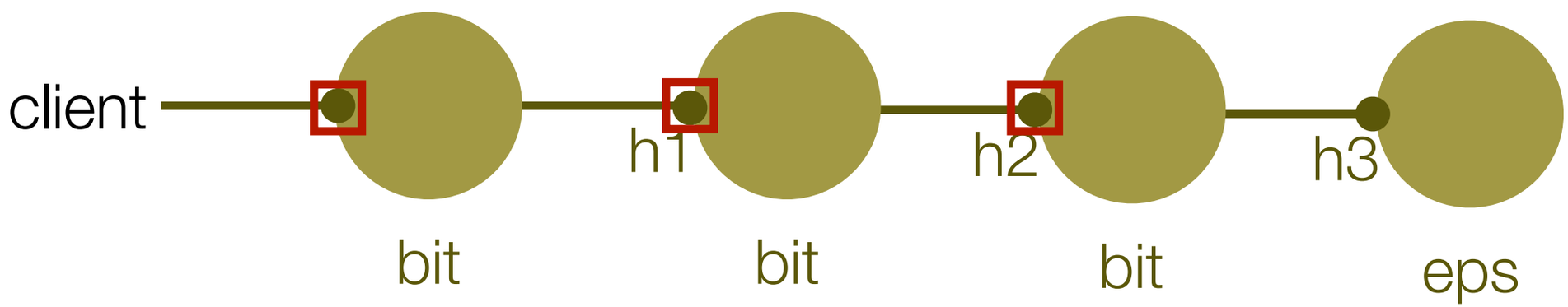
offering channel



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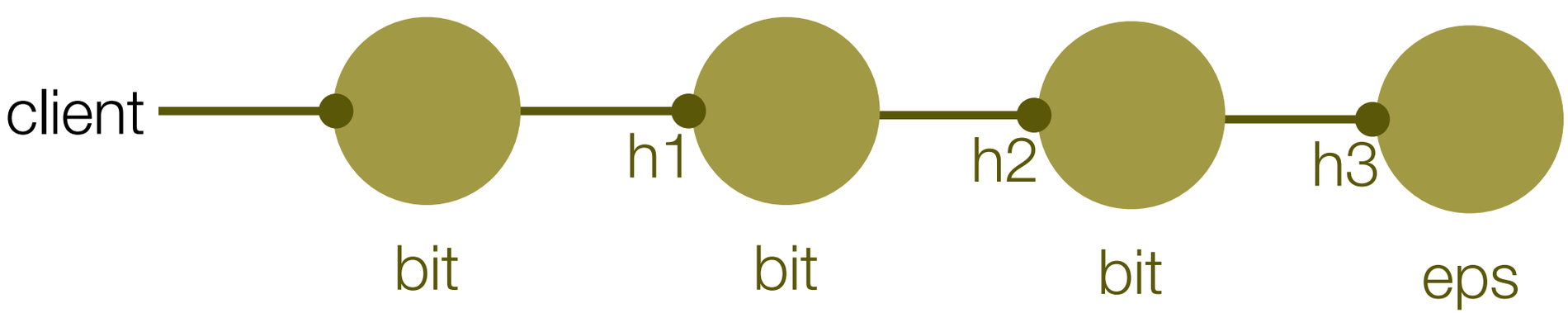

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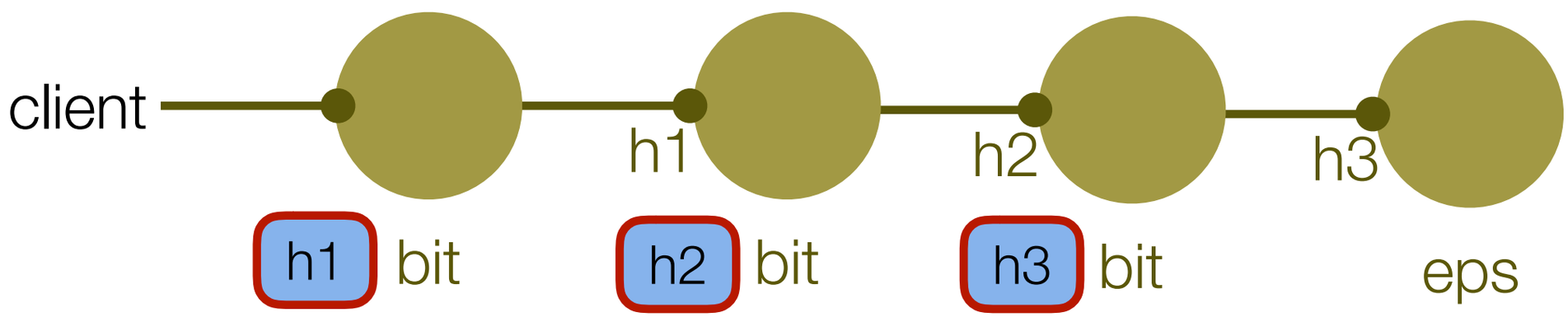
channel resources



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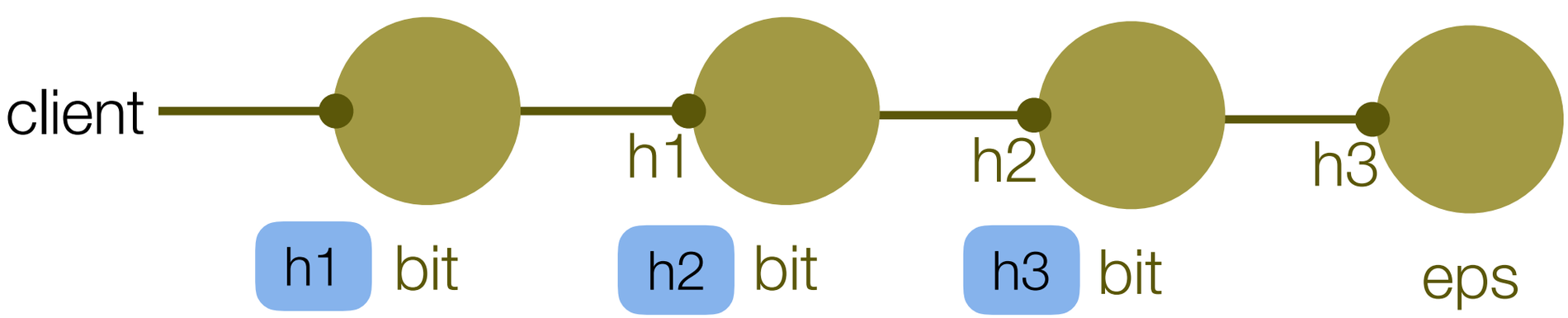

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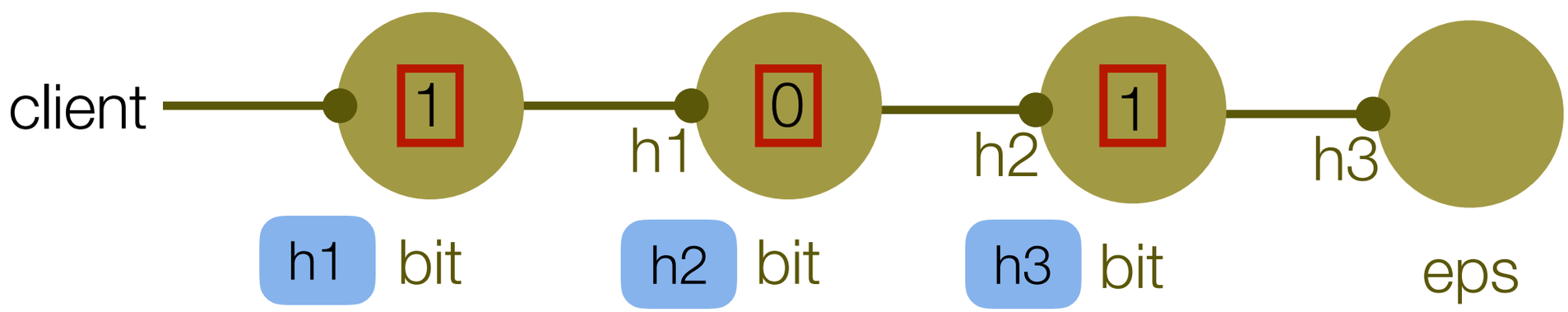
local state



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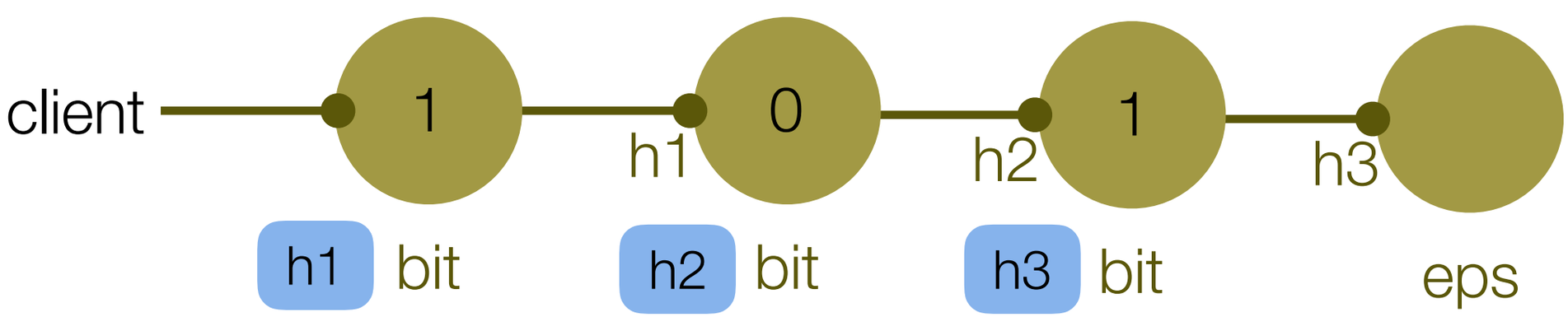

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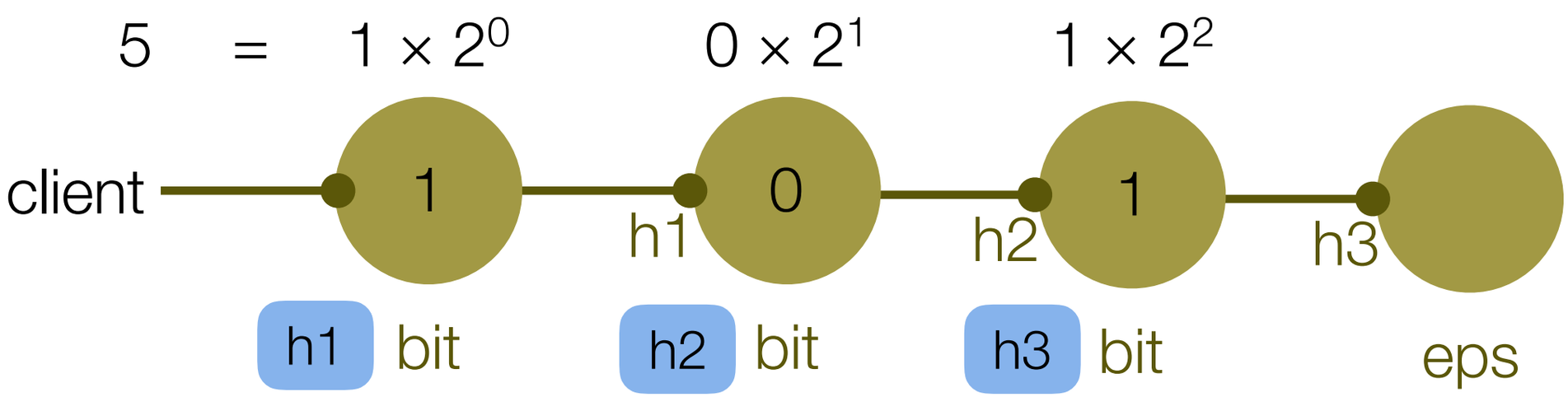

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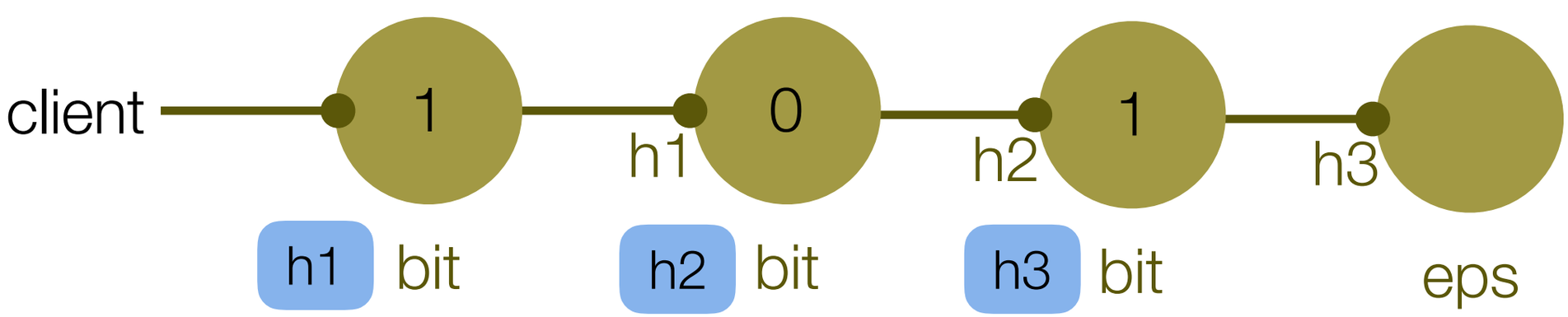

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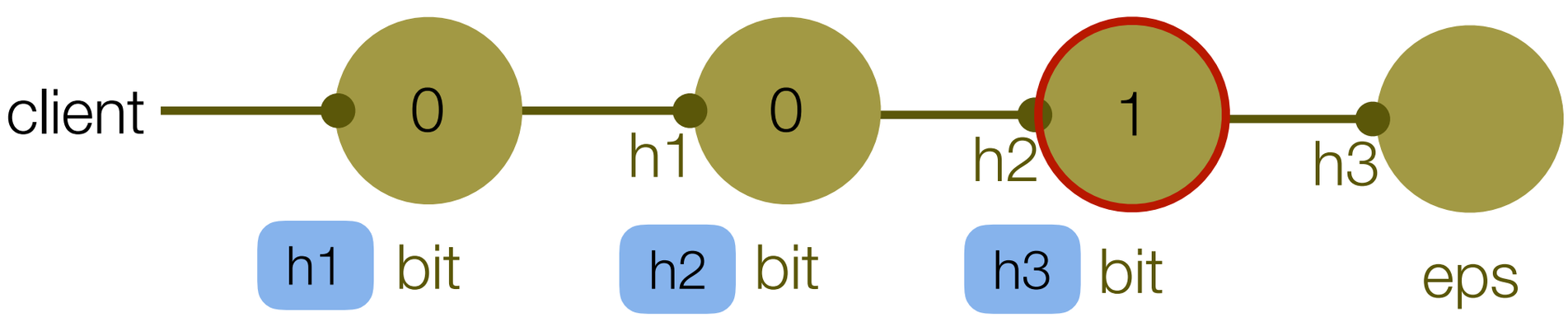

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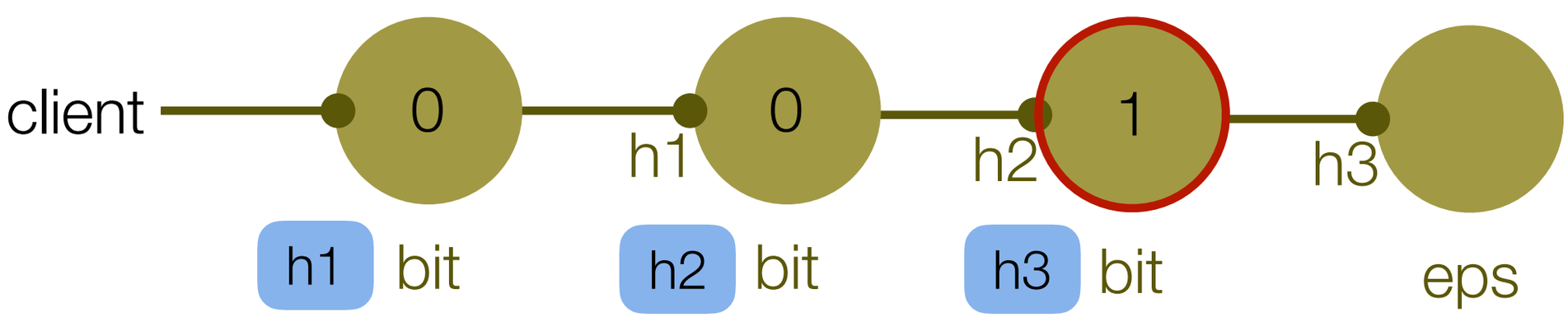

Process implementations in CLOO

session type:

```
typedef <?choice ctr> ctr;
choice ctr {<ctr> Inc; <!int; > Val;};
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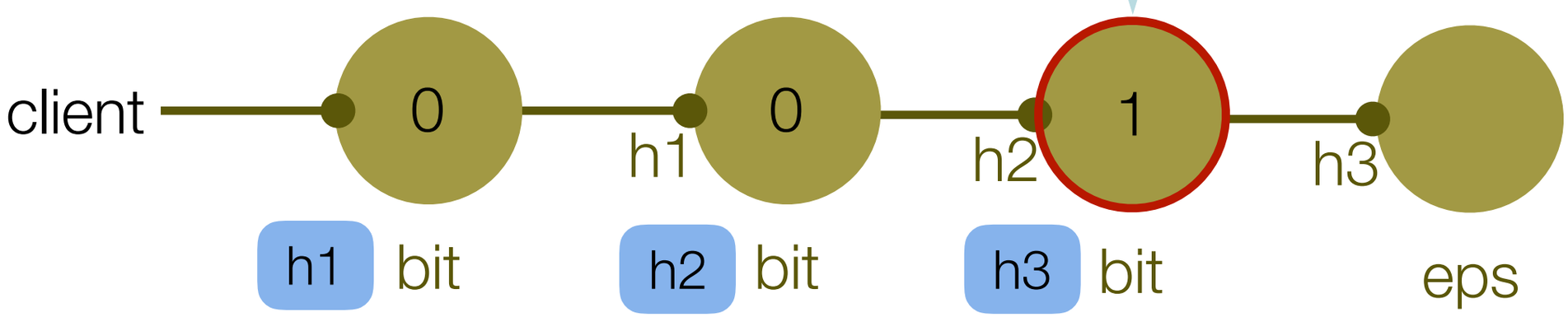
process implementation as bit string:

```
ctr $l bit(bool b, ctr $h) {
  loop {
    switch ($l) {
      case Inc: … ;
      case Val: … ;
}}}
```

```
if (b == false) {
  b = true;
} else {
  $h.Inc;
  b = false;
}
```



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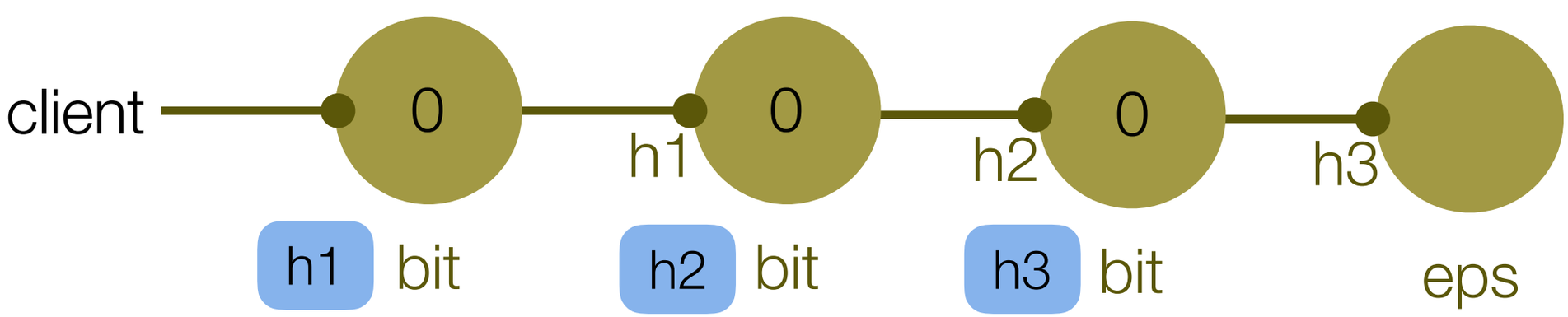

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ctr $l eps() {
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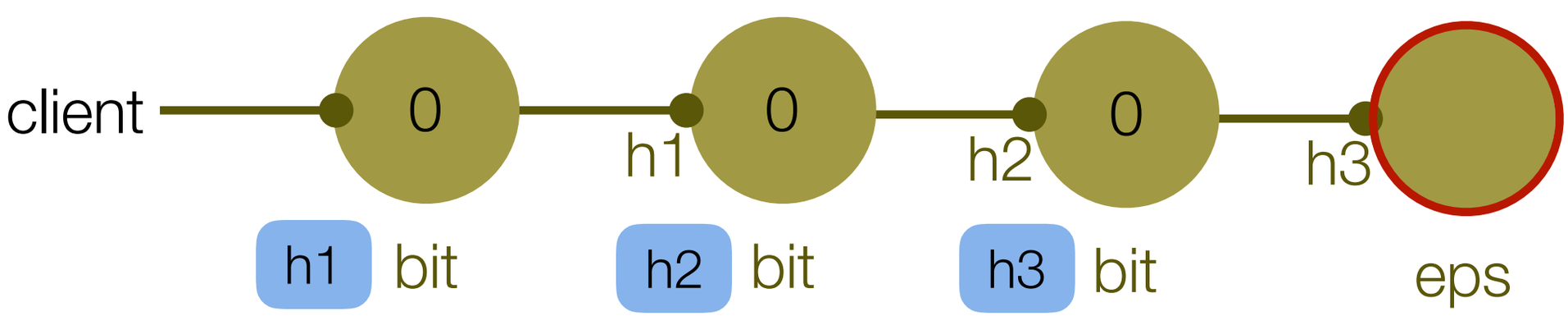

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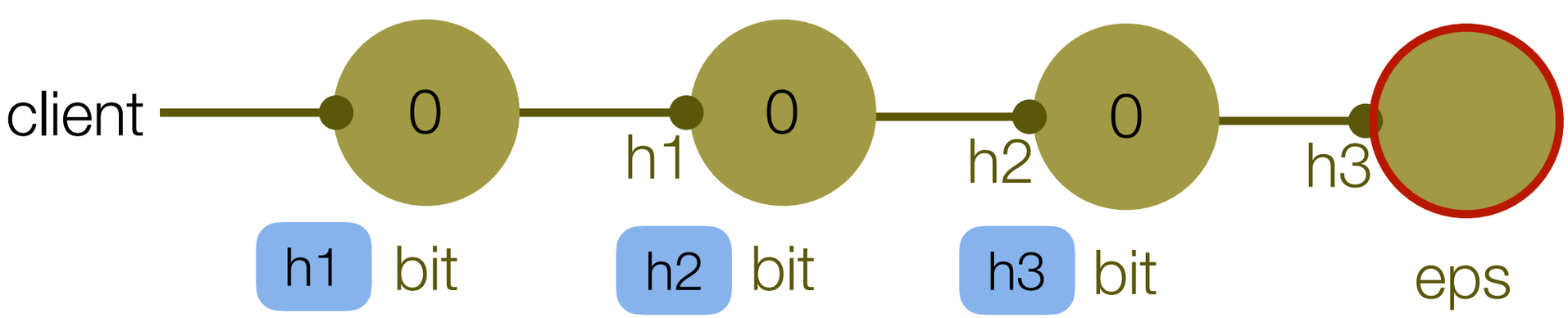

Process implementations in CLOO

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typedef <?choice ctr> ctr;
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process implementation as bit string:

```
ctr $z = eps();
$l = bit(true, $z);
```

```
ctr $l eps() {
  loop {
    switch ($l) {
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}}}
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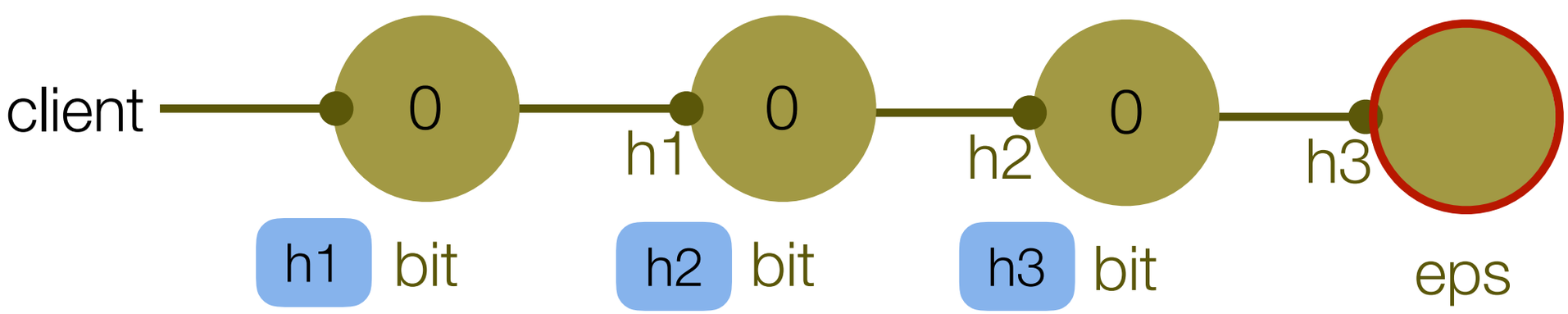

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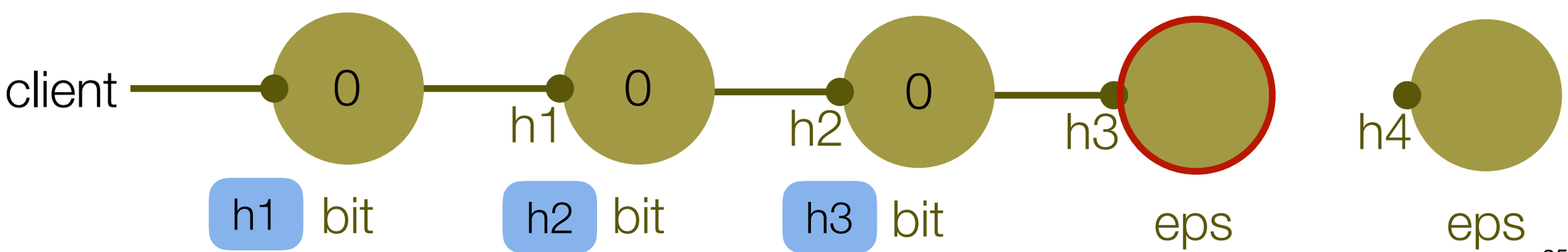

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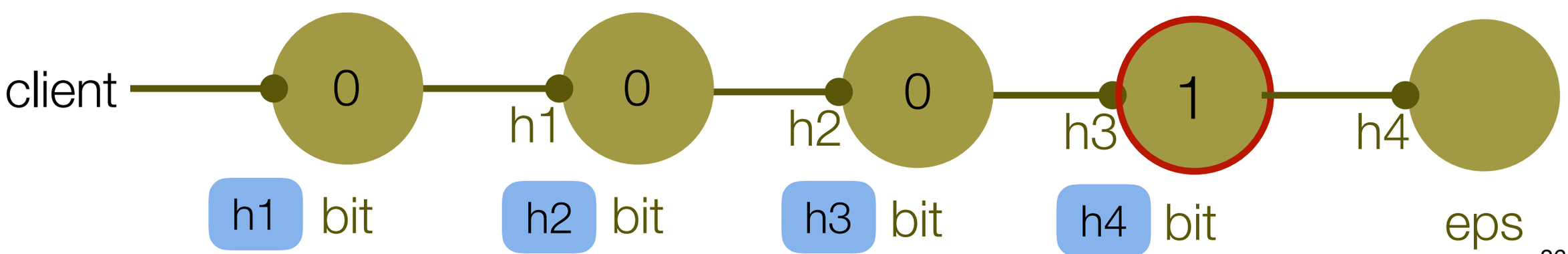

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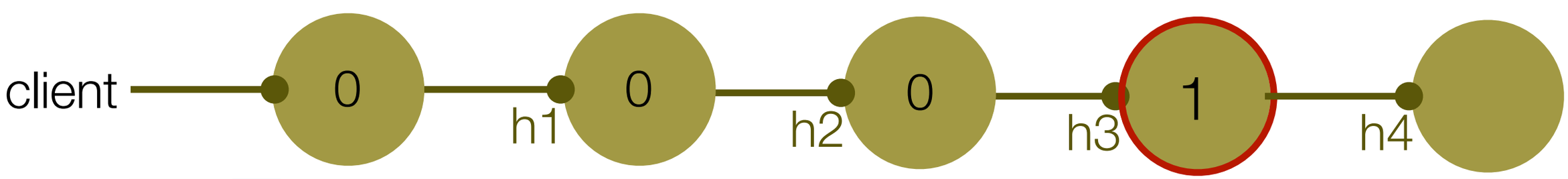

Dynamic dispatch of labels

Basic correspondence

- Objects as processes

A process has state and identity. Process state: local + protocol.

- Processes are encapsulated

Process local state can only be read or written by process.

Protocol state can only be changed by message exchange.

- Method invocations as receives of labels from external choice

Processes also permit sends of labels from internal choice.

- References as channels

Channels are bidirectional and linear. Ownership transfer possible.

Structural subtyping

```
typedef <?choice ctr> ctr;
choice ctr {<ctr> Inc; <!int; > Val;};
```

Structural subtyping

supertype:

```
typedef <?choice ctr> ctr;
choice ctr {<ctr> Inc; <!int; > Val;};
```

subtype:

```
typedef <?choice ctr_inc2> ctr_inc2;
choice ctr_inc2 {
  <ctr_inc2>       Inc;
  <ctr_inc2>       Inc2;
  <!int; >         Val;
};
```

Structural subtyping

supertype:

```
typedef <?choice ctr> ctr;
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subtype:

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typedef <?choice ctr_inc2> ctr_inc2;
choice ctr_inc2 {
  <ctr_inc2>       Inc;
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};
```

ctr_inc2 is a subtype of ctr, it accepts at least same choices

Structural subtyping

supertype:

```
typedef <?choice ctr> ctr;
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subtype:

```
typedef <?choice ctr_inc2> ctr_inc2;
choice ctr_inc2 {
  <ctr_inc2>      Inc;
  <ctr_inc2>      Inc2;
  <!int; >        Val;
};
```

- ctr_inc2 is a subtype of ctr, it accepts at least same choices
- subtyping arises between external and internal choices

Outline

Background: linear session types

Basic correspondence between CLOO - object-oriented concepts:

- Objects as processes
- Dynamic dispatch
- Structural subtyping

New forms of expression:

- Type-directed delegation
- Internal Choice

Conclusions

Type-directed delegation

supertype:

```
typedef <?choice ctr> ctr;
choice ctr {<ctr> Inc; <!int; > Val;};
```

subtype:

```
typedef <?choice ctr_inc2> ctr_inc2;
choice ctr_inc2 {
  <ctr_inc2>      Inc;
  <ctr_inc2>      Inc2;
  <!int; >        Val;
};
```

Type-directed delegation

supertype:

```
typedef <?choice ctr> ctr;
choice ctr {<ctr> Inc; <!int; > Val;};
```

subtype:

```
typedef <?choice ctr_inc2> ctr_inc2;
choice ctr_inc2 {
  <ctr_inc2>      Inc;
  <ctr_inc2>      Inc2;
  <!int; >        Val;
};
```

process:

```
ctr_inc2 $c counter_inc2(ctr $d) {
  loop {
    switch ($c) {
      case Inc2: $d.Inc; $d.Inc; break;
      default:
        $c <=> $d; // type-directed delegation to ‘d'
}}}
```

Type-directed delegation

supertype:

```
typedef <?choice ctr> ctr;
choice ctr {<ctr> Inc; <!int; > Val;};
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typedef <?choice ctr_inc2> ctr_inc2;
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typedef <?choice ctr> ctr;
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```
typedef <?choice ctr_inc2> ctr_inc2;
choice ctr_inc2 {
  <ctr_inc2>      Inc;
  <ctr_inc2>      Inc2;
  <!int; >        Val;
};
```

inferable from session type declaration and subtyping relationship

```
nc2(ctr $d) {

    case Inc2: $d.Inc; $d.Inc; break;
    default:
      $c <=> $d; // type-directed delegation to ‘d'
}}}
```

Internal choice

bit string as external choice:

```
typedef <?choice ctr> ctr;
choice ctr {<ctr> Inc; <!int; > Val;};
```

bit string as internal choice:

```
typedef <!choice bits> bits;
choice bits {<> Eps; <!bool; bits> Bit;};
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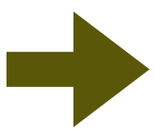

Bit string is represented in terms of Bit and Eps messages, rather than bit and eps processes

External vs internal choice

bit string as external choice:

```
typedef <?choice ctr> ctr;
choice ctr {<ctr> Inc; <!int; > Val;};
```

```
ctr $l bit(bool b, ctr $h) {
 …
}
```

```
ctr $l eps() {
  …
}
```

bit string as internal choice:

```
typedef <!choice bits> bits;
choice bits {<> Eps; <!bool; bits> Bit;};
```

```
bits $succ inc(bits $ctr) {…}
```

```
<!int;> $val val(bits $ctr) {…}
```

```
bits $zero zero() {…}
```

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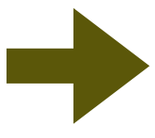

Lead to different program modularization

External vs internal choice

bit string as external choice:

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```
ctr $l bit(bool b, ctr $h) {
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}
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```
ctr $l eps() {
  …
}
```

bit string as internal choice:

```
typedef <!choice bits> bits;
choice bits {<> Eps; <!bool; bits> Bit;};
```

→ Lead to different program modularization

→ External choice facilitates addition of new variants, internal choice addition of new operations

Conclusions

A fresh look at object-oriented programming

- accommodates existing and new object-oriented features
- inherently concurrent and protocol-aware

Ongoing work:

- compiler support of subtyping and type-directed delegation
- extend formalization

Future work:

- polymorphism for generic data structures
- affine and shared channels
- shared channels combined with traditional locking primitives