Modular I/O Reasoning in DimSum

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Modular I/O Reasoning

```
int echo () :=
  let c := getc();
  putc(c);
  return 0;
```

```
{...}
echo
{...}
```

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$$\{\lambda\ \mathsf{es},\ \ulcorner \mathsf{es} = [\ ] \urcorner\}$$
$$\texttt{echo}$$
$$\{\lambda\ \mathsf{v},\ \ulcorner \mathsf{v} = 0 \urcorner\}$$

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$$\Big\{\lambda\ \mathsf{es},\ \ulcorner \mathsf{es} = [\ ] \urcorner * \{\lambda\ \mathsf{es},\ \ulcorner \mathsf{es} = [\ ]\urcorner\}\mathtt{getc}\{\lambda\ \mathsf{v},\ \{\lambda\ \mathsf{es},\ \ulcorner \mathsf{es} = \mathsf{v}\urcorner\}\mathtt{putc}\{\_\}\ \}\Big\}$$

$$\mathtt{echo}$$

$$\Big\{\lambda\ \mathsf{v},\ \ulcorner \mathsf{v} = 0 \urcorner\Big\}$$

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$$\texttt{echo}$$

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$$\{\lambda\ \mathsf{es},\ \exists\ \mathsf{v},\ \ulcorner \mathsf{es} = \mathsf{v} \urcorner * \mathsf{P}\ (\mathsf{v} + 1)\}\ \texttt{putc}\ \{\lambda\ \mathsf{ret},\ \mathsf{P}\ (\mathsf{v} + 1)\}$$

$$\{\lambda\ \mathsf{es},\ \ulcorner \mathsf{es} = [\ ] \urcorner * \exists\ \mathsf{v},\ \mathsf{P}\ \mathsf{v}\}\ \texttt{getc}\ \{\lambda\ \mathsf{ret},\ \ulcorner \mathsf{ret} = \mathsf{v} \urcorner * \mathsf{P}\ (\mathsf{v} + 1)\}$$

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$$\texttt{echo}$$

$$\{\lambda\ \mathsf{v},\ \ulcorner \mathsf{v} = 0 \urcorner\}$$

DimSum

- Decentralized/language-agnostic multi-language semantics
  - No fixed source
  - No fixed set of languages
  - No fixed memory model
  - No fixed notion of linking
- Program semantics as LTS, interaction via synchronization
  - Reason locally in terms of interaction of two modules
- Notion of semantic linking: $\oplus$
  - Link semantic components (modules) rather than syntactic
  - Link programs with specifications (abstract program)

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Proofs in DimSum

$$\boxed{[\![\mathsf{echo}_{\mathsf{rec}} \quad \oplus \quad \mathsf{getc}_{\mathsf{spec}}]\!]} \preceq \quad [\![\mathsf{echo}_{\mathsf{spec}}]\!]$$

Proofs in DimSum

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int echo () :=
  let c := getc();
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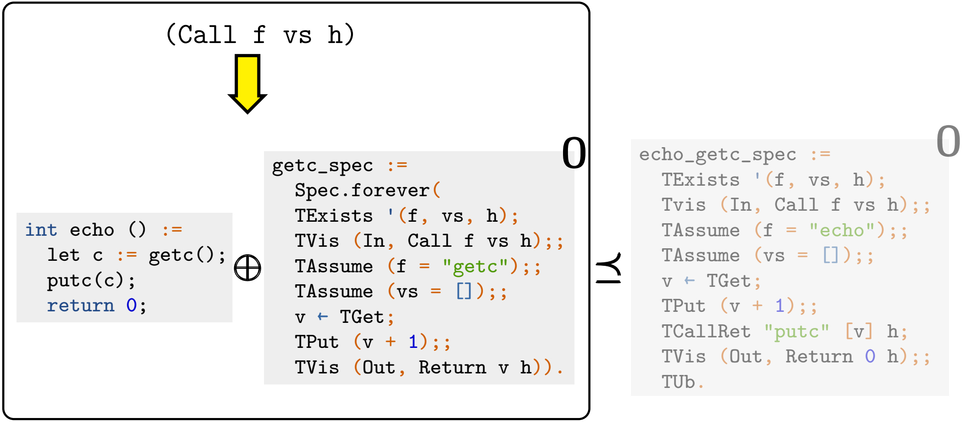

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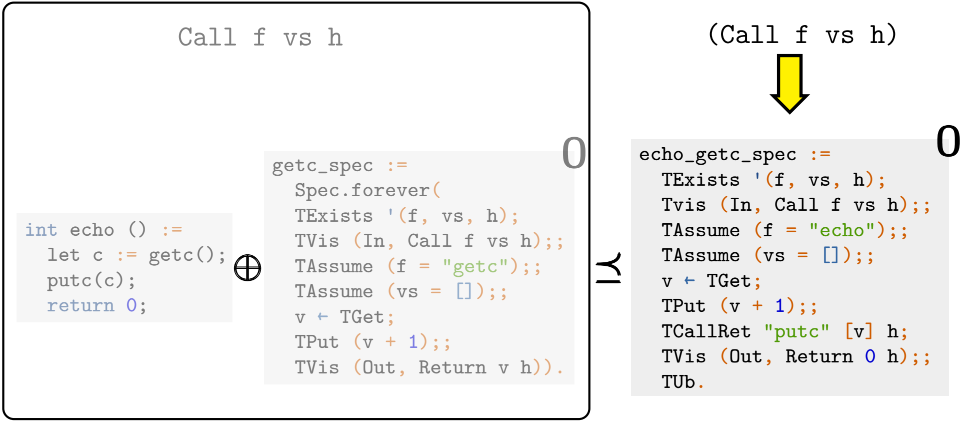

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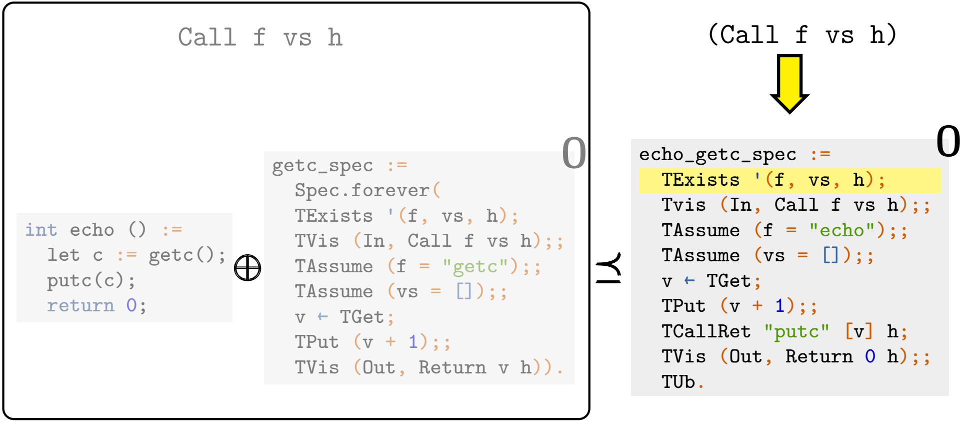

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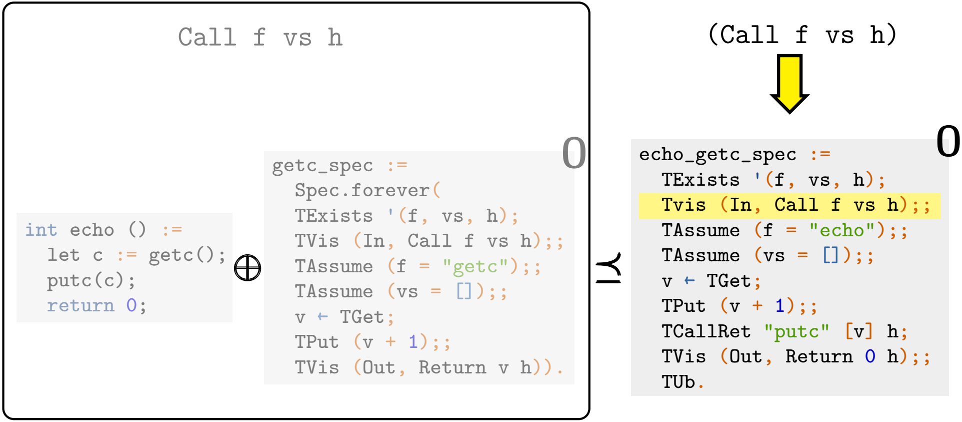

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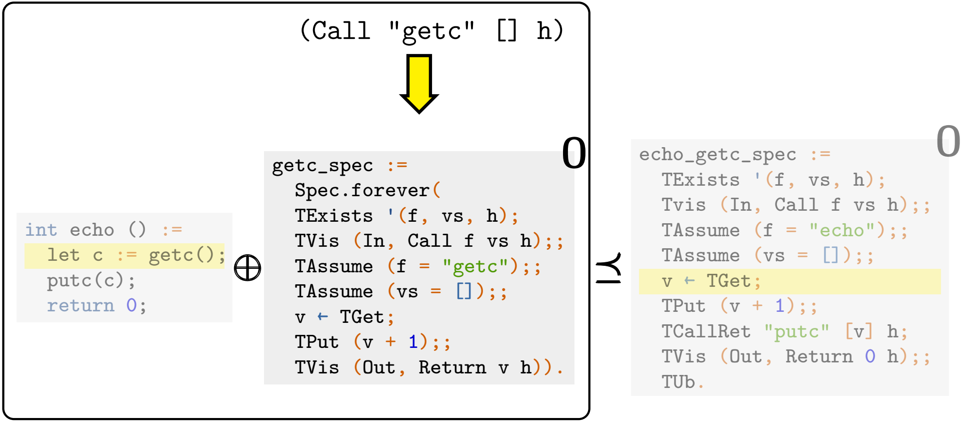

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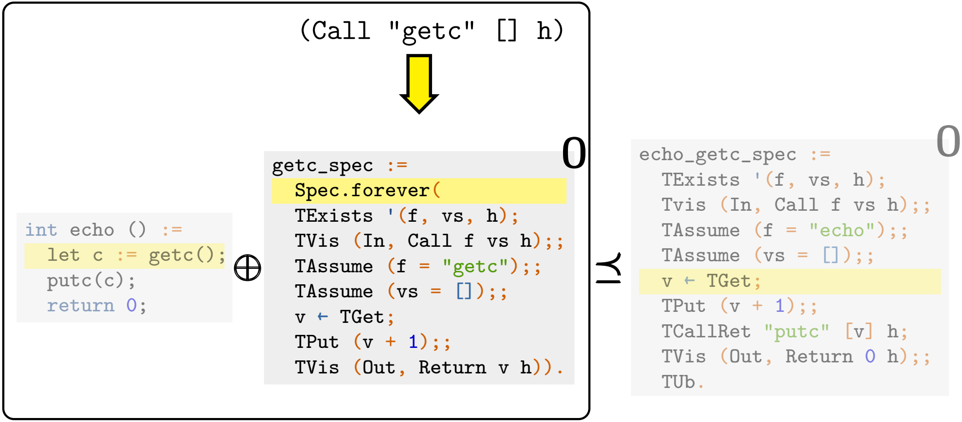

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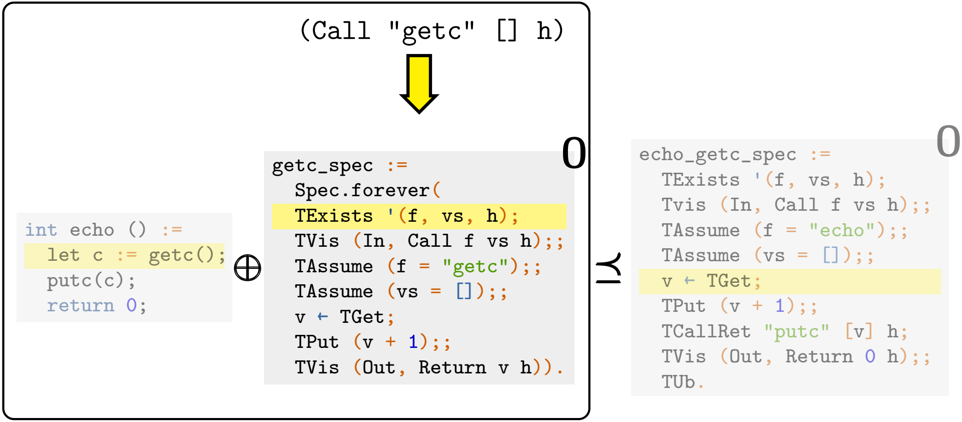

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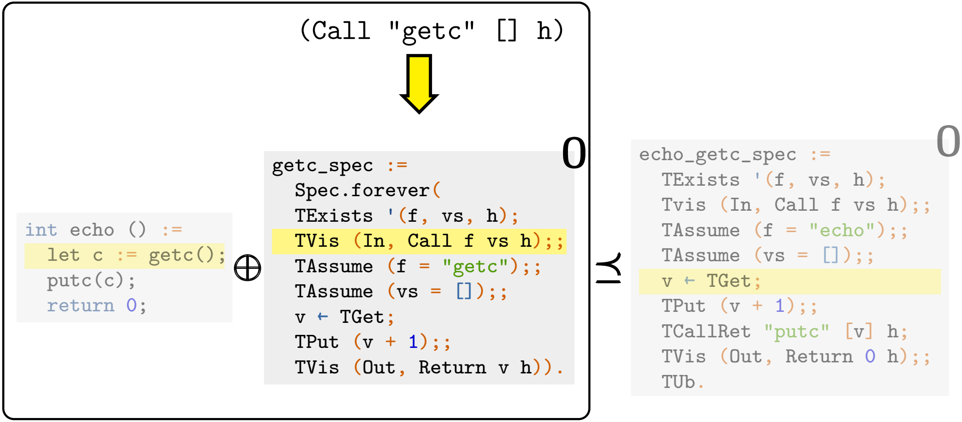

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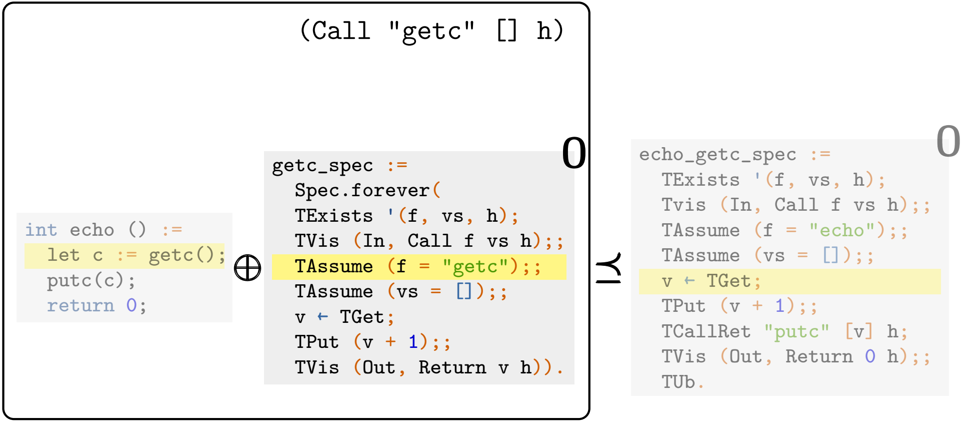

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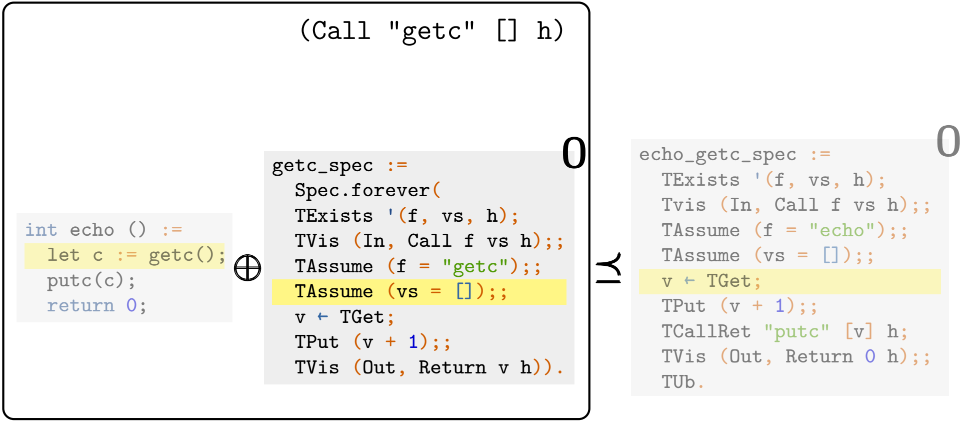

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```

⪯

0

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echo_getc_spec :=
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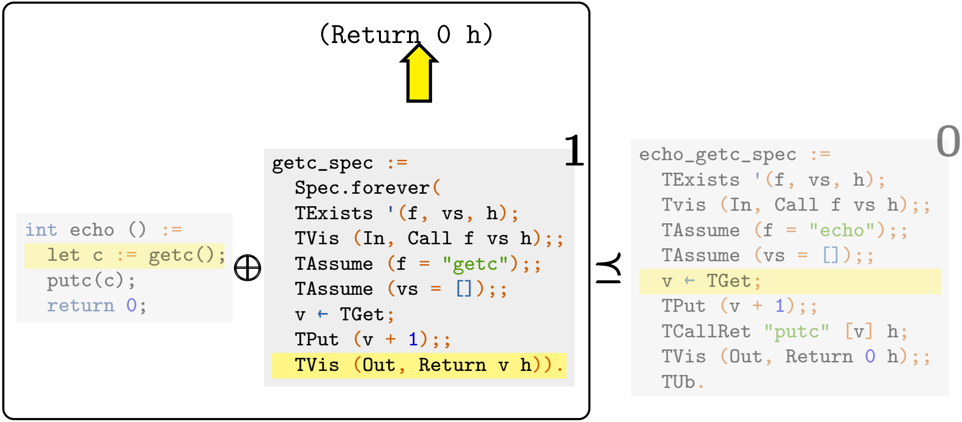
```

Proofs in DimSum



(Return 0 h)

```
int echo () :=
  let c := getc();
  putc(c);
  return 0;
```

⊕

1

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getc_spec :=
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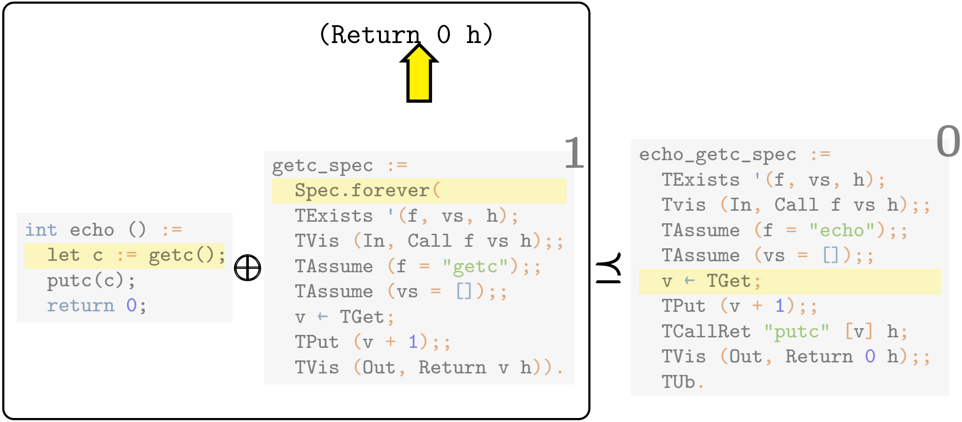
Proofs in DimSum



```
(Return 0 h)
```

```
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≼

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Proofs in DimSum

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```

⇩

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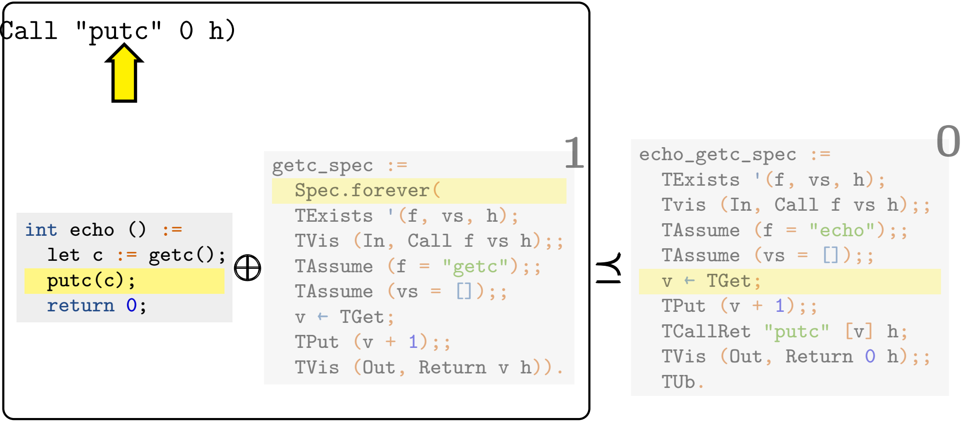
Proofs in DimSum



```
Call "putc" 0 h)
```

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⊕

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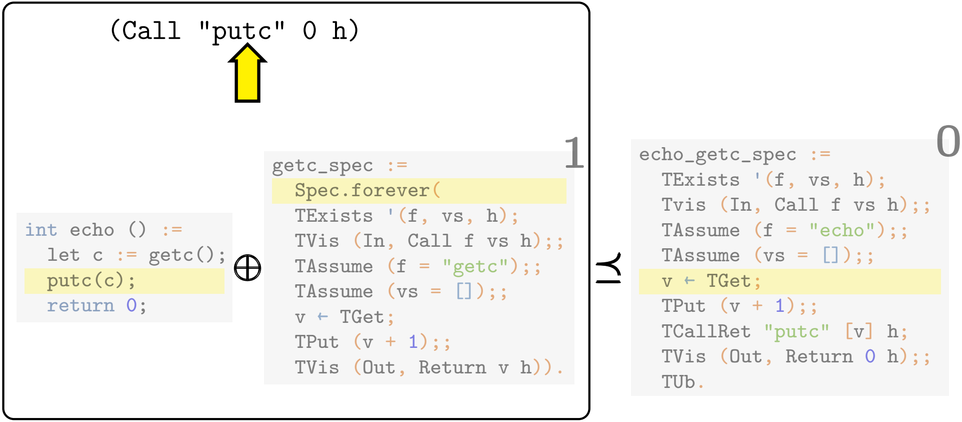
0

Proofs in DimSum



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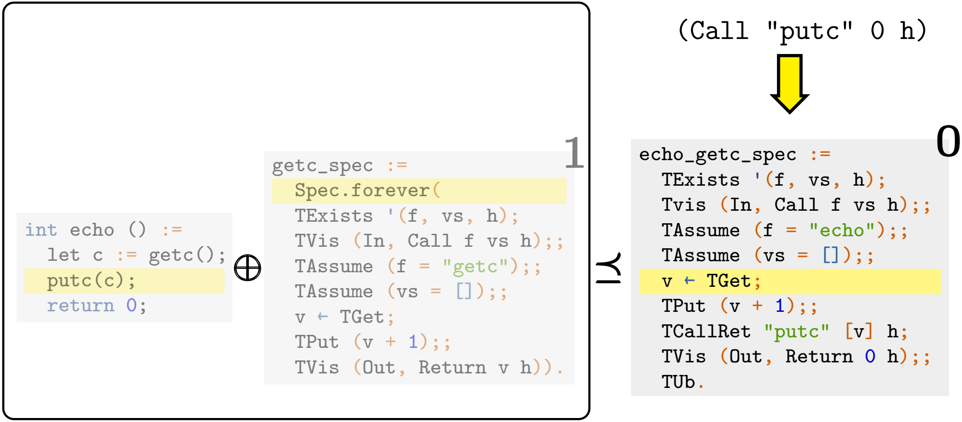
Proofs in DimSum



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```

⊕

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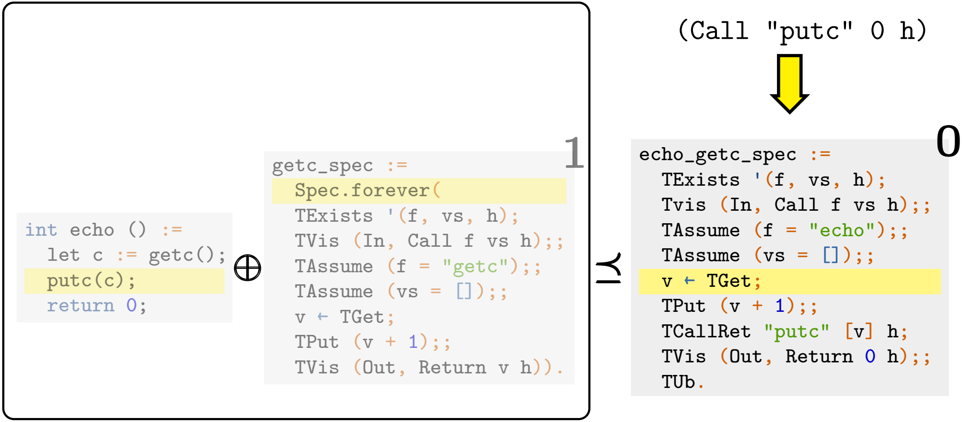
0

Proofs in DimSum



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$\oplus$

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```

1

$\preceq$

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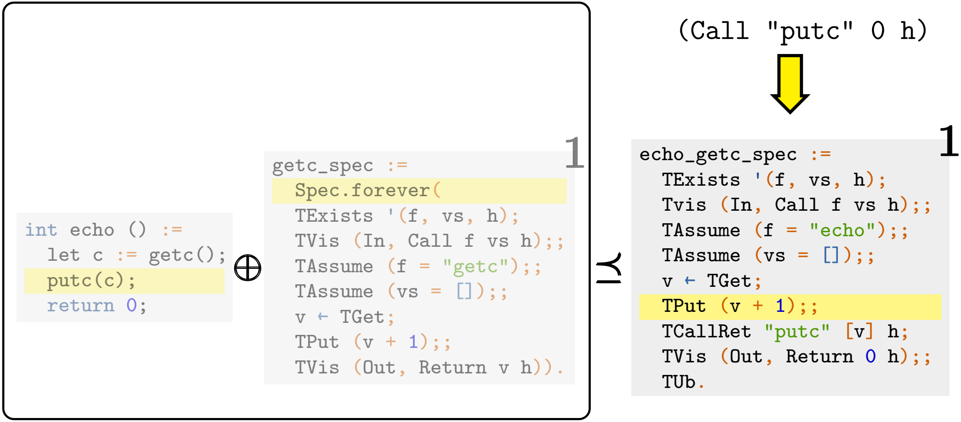
0

Proofs in DimSum



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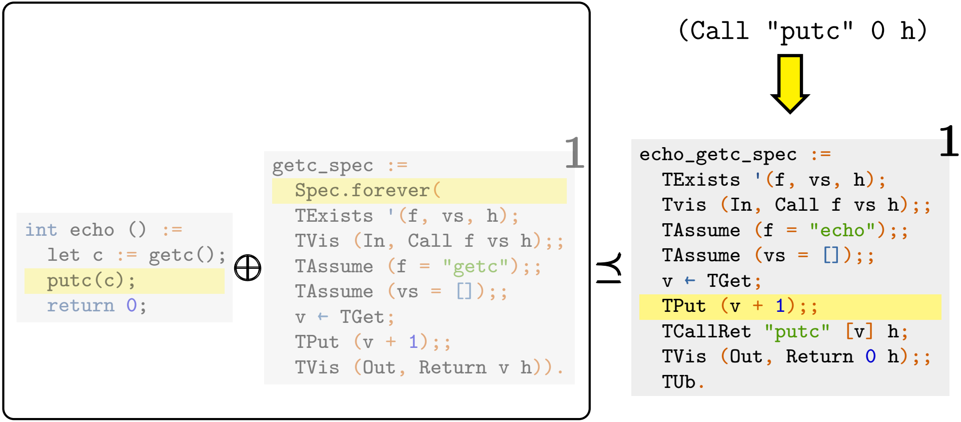
Proofs in DimSum



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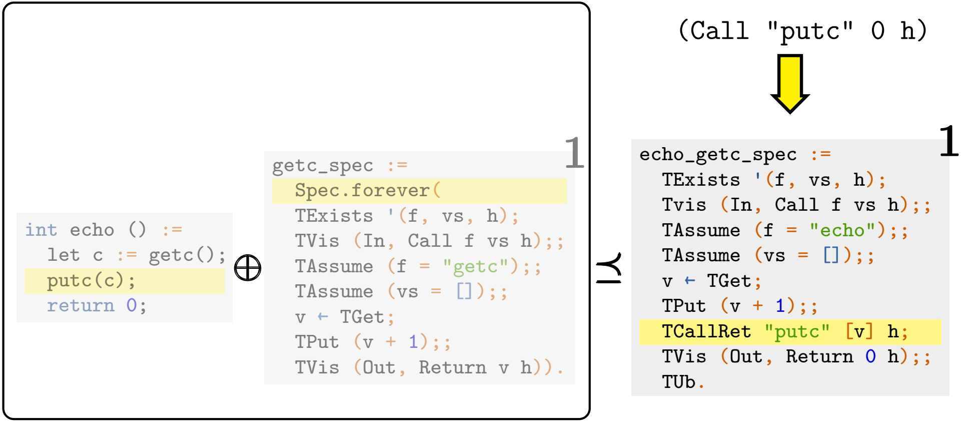
Proofs in DimSum



(Call "putc" 0 h)

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```

Proofs in DimSum

(Return v h)

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```

$\oplus$

```
getc_spec :=
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1

$\preceq$

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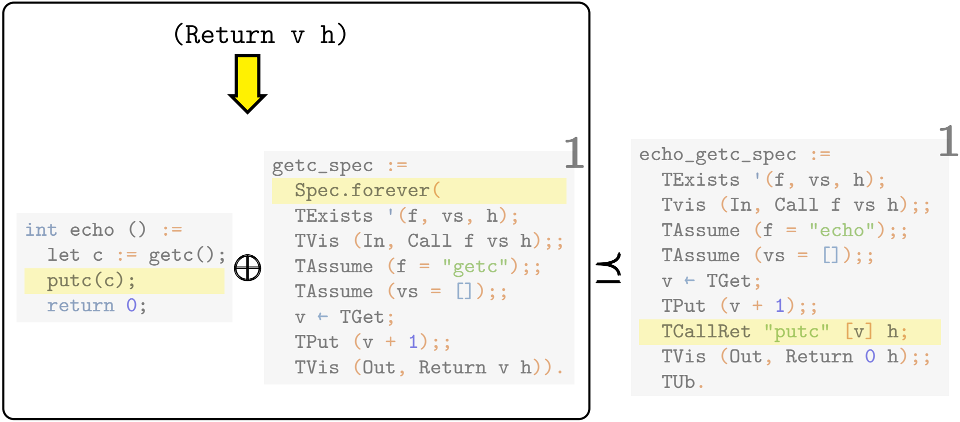
1

Proofs in DimSum



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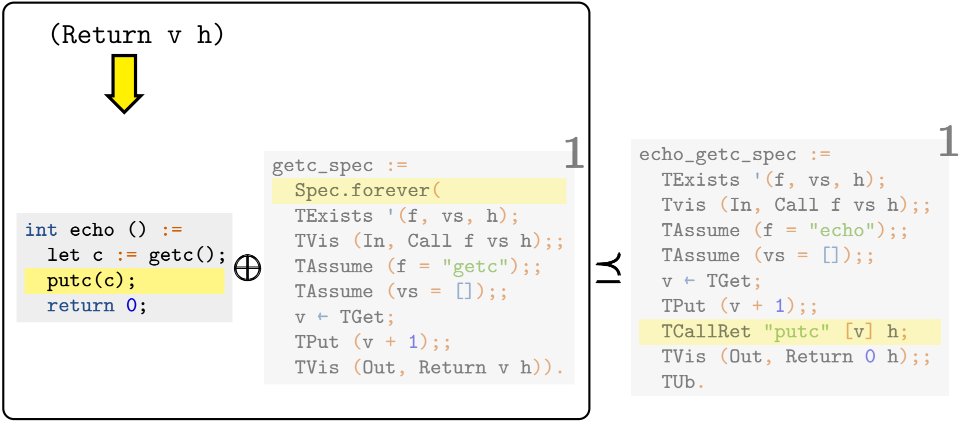
Proofs in DimSum



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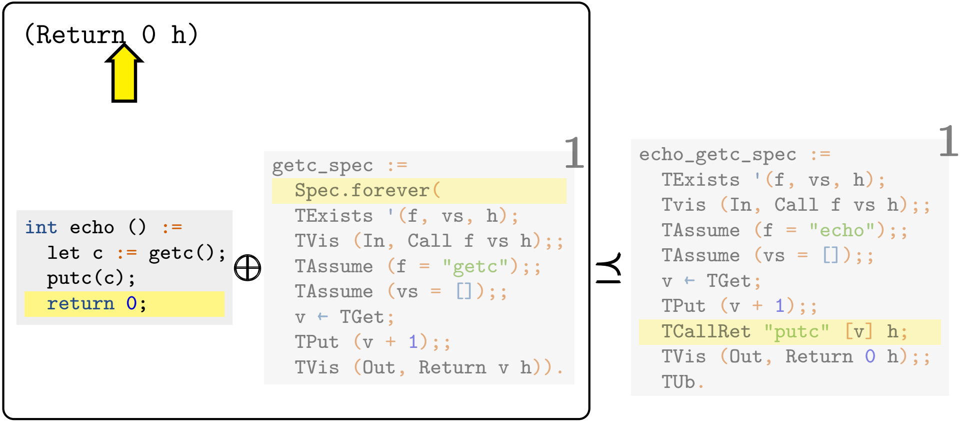
Proofs in DimSum



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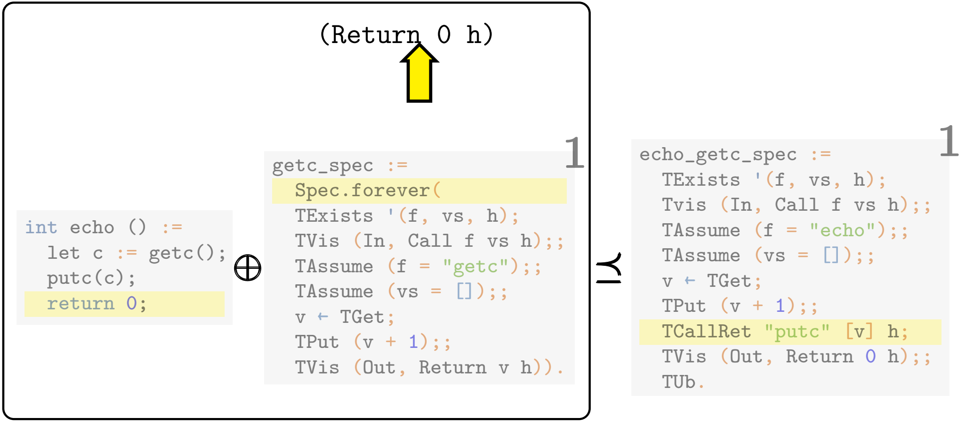

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Proofs in DimSum

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⪯

(Return 0 h)

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Proofs in DimSum

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Towards Hoare-style Reasoning

$$[\![\mathsf{echo}_{\mathsf{rec}} \oplus \mathsf{getc}_{\mathsf{spec}}]\!] \quad \preceq \quad [\![\mathsf{echo}_{\mathsf{spec}}]\!]$$

Towards Hoare-style Reasoning

$[\![\textcolor{red}{\mathsf{echo}_{\mathsf{rec}}} \oplus \mathsf{getc}_{\mathsf{spec}}]\!] \approx\!> (\boldsymbol{\lambda} \kappa_t \sigma_t,$

Towards Hoare-style Reasoning

$\llbracket \mathsf{echo}_{\mathsf{rec}} \oplus \mathsf{getc}_{\mathsf{spec}} \rrbracket \approx\!> (\boldsymbol{\lambda} \kappa_t \, \sigma_t, \llbracket \mathsf{echo}_{\mathsf{spec}} \rrbracket \approx\!> (\boldsymbol{\lambda} \kappa_s \, \sigma_s,$

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$$[\![\textcolor{red}{\mathsf{echo}_{\mathsf{rec}}} \oplus \mathsf{getc}_{\mathsf{spec}}]\!] \approx\!> (\boldsymbol{\lambda} \kappa_t \sigma_t, [\![\mathsf{echo}_{\mathsf{spec}}]\!] \approx\!> (\boldsymbol{\lambda} \kappa_s \sigma_s, \kappa_t = \kappa_s * \sigma_t \preceq \sigma_s))$$

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$$[\![\text{echo}_{\text{rec}}]\!] \approx> \Pi$$

TGT Call “echo” es @ Π $\{\{\Phi\}\}$

Rotation Project

- Get familiar with DimSum (and Iris)
- Experiment with new reasoning style
- Proof refinements for multiple example programs

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```
int echo () :=
  let c := getc();
  putc(c);
  return 0;
```

```
int getc (l) :=
  let _ := read(l);
  return *l;
```

```
void echo () :=
  let c := getc();
  putc(c);
  echo ();
```

```
global pos = 0;
read (l, c) :=
  if (c <= 0) {
    return 0;
  } else {
    l <- *pos;
    pos <- *pos + 1;
    ret = read(l + 1, c -1);
    return ret + 1;
  }
```

```
int echo () :=
  let c := getc();
  putc(c);
  let c := getc();
  putc(c);
  return 0;
```

(Modular) Hoare-style Reasoning

```
TGT Call "echo" es @ ∏
  PRE |-∗: es POST_e, ⌜es = []⌝ ∗
    TGT Call "getc" es @ ∏
      PRE |-∗: es POST, ⌜es = []⌝ ∗
      POST |∗: ret,
        TGT Call "putc" es @ ∏
          PRE |-∗: es POST, ⌜es = [v]⌝ ∗
          POST |∗: _,
  POST_e |∗: ret, ⌜ret = 0⌝.
```

(Modular) Hoare-style Reasoning

```
TGT Call "getc" es @ Π
  PRE |-∗: es POST, ∃ v, P v ∗ ⌜es = []⌝ ∗
  POST |∗: ret, ⌜ret = v⌝ ∗ P (v + 1).
```

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      POST |∗: _, P (v + 1) (∗)
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```

Example 1

$$\llbracket \text{echo}_{\text{rec}} \oplus \text{getc}_{\text{spec}} \rrbracket \preceq \llbracket \text{echo}_{\text{spec}} \rrbracket$$

```
Lemma sim_getc_spec `{!specGS} Π Φ :
  switch Π
    PRE |-∗: κ σ1 POST,
      ∃ f es h, ⌜κ = Some (Incoming, ERCall f es h)⌝ ∗
    POST Tgt _ _ |∗: σ' Π',
      ∃ v, ⌜f = "getc"⌝ ∗ ⌜es = []⌝ ∗ spec_state v ∗ ⌜σ' = σ1⌝ (∗)
  switch Π'
    PRE |-∗: κ σ POST,
      ⌜κ = Some (Outgoing, ERReturn (ValNum v) h)⌝ ∗ spec_state (v + 1) ∗
    POST Tgt _ _ |∗: σ' Π'',
      ⌜σ' = σ⌝ ∗ ⌜Π'' = Π⌝ ∗ TGT getc_spec @ Π {{ Φ }} -∗
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Example 2

$$\llbracket \mathrm{echo}_{\mathrm{rec}} \oplus \mathrm{getc}_{\mathrm{spec}} \rrbracket \preceq \llbracket \mathrm{echo}_{\mathrm{spec}} \rrbracket$$

```
Lemma sim_getc fns Π_l Π_r PL σi :
  "getc" ↪ None -∗
  PL σi -∗
  ⌜σi.1 ≡ getc_spec⌝ -∗
  ⌜σi.2 = 0⌝ -∗
  □ switch_linked_fixed Tgt Π_l Π_r
      PRE |-∗: σ_l POST, ∃ h v σg, PL σg ∗
      POST (ERCall "getc" [] h) σg |∗: σr Π_r',
    switch_link Tgt Π_r'
      Pre |-∗: σ_r' POST, ∃ h'
      POST (ERReturn (ValNum v) h') _ σ_l |∗: _ Π_l',
        ⌜Π_l' = Π_l⌝ ∗ PL σ_r' ==∗
  ∃ P, P 0 ∗ □ rec_fn_spec_hoare Tgt Π_l "getc" (getc_fn_spec P).
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      POST (ERReturn (ValNum v) h') _ σ_l |∗: _ Π_l',
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  "getc" ↪ None -∗
  PL σi -∗
  ⌜σi.1 ≡ getc_spec⌝ -∗
  ⌜σi.2 = 0⌝ -∗
  □ switch Π_l
      PRE |-∗: κ σ0 POST, ∃ h v σg, PL σg ∗
      POST Tgt _ _ |∗:  σi0 Πi, ⌜σi0 = σg⌝ ∗ ⌜Πi = Π_r⌝ ∗
    switch Πi
      PRE |-∗: κ' σ POST0, ∃ e' : rec_ev, ⌜κ' = Some (Incoming, e')⌝ ∗
      POST0 Tgt _ _ |∗: σr Πr, ⌜σr = σ⌝ ∗ ⌜e' = ERCall "getc" [] h⌝ ∗
    switch Πr
      PRE |-∗: κ0 σ1 POST1, ∃ h', ⌜κ0 = Some (Outgoing, ERReturn v h')⌝ ∗
      POST1 Tgt _ _ |∗: σi1 Πi0, ⌜σi1 = σ0⌝ ∗
    switch Πi0
      PRE |-∗: κ'0 σ2 POST2, ∃ e'0, ⌜κ'0 = Some (Incoming, e'0)⌝ ∗
      POST2 Tgt _ _ |∗: σr0 Πr0,
        ⌜σr0 = σ2⌝ ∗ ⌜e'0 = ERReturn v h'⌝ ∗ ⌜Πr0 = Π_l⌝ ∗ PL σ1 ==∗
  ∃ P, P 0 ∗ □ rec_fn_spec_hoare Tgt Π_l "getc" (getc_fn_spec P).
```

Outcome & Takeaways

- Lemma for `TCallRet`
- Keep Πs the same - new lemmas for linking
- Balance between Abstraction and Information
- Balance between Hacking and Thinking