Exact and Linear-Time Gas-Cost Analysis

Ankush Das* (Carnegie Mellon University)
Shaz Qadeer (Facebook)

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What are Smart Contracts?

- Programs to digitally facilitate the execution of a transaction between distrusting parties
- Transactions are executed by third-party miners and stored on a global distributed ledger, or blockchain
- User pays for the execution cost of transaction in gas units

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set standard assigns cost to each operation

Execution Model

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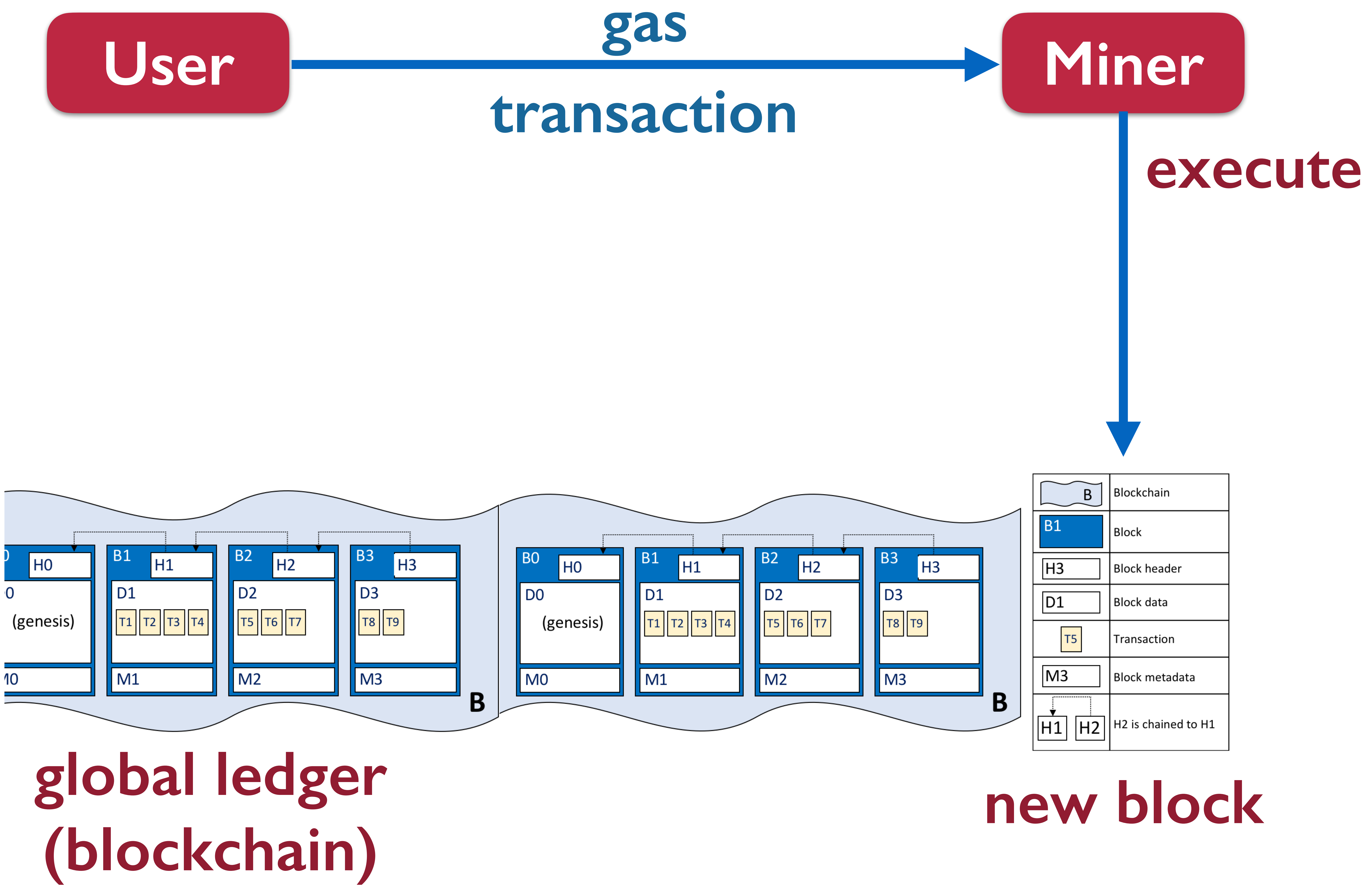

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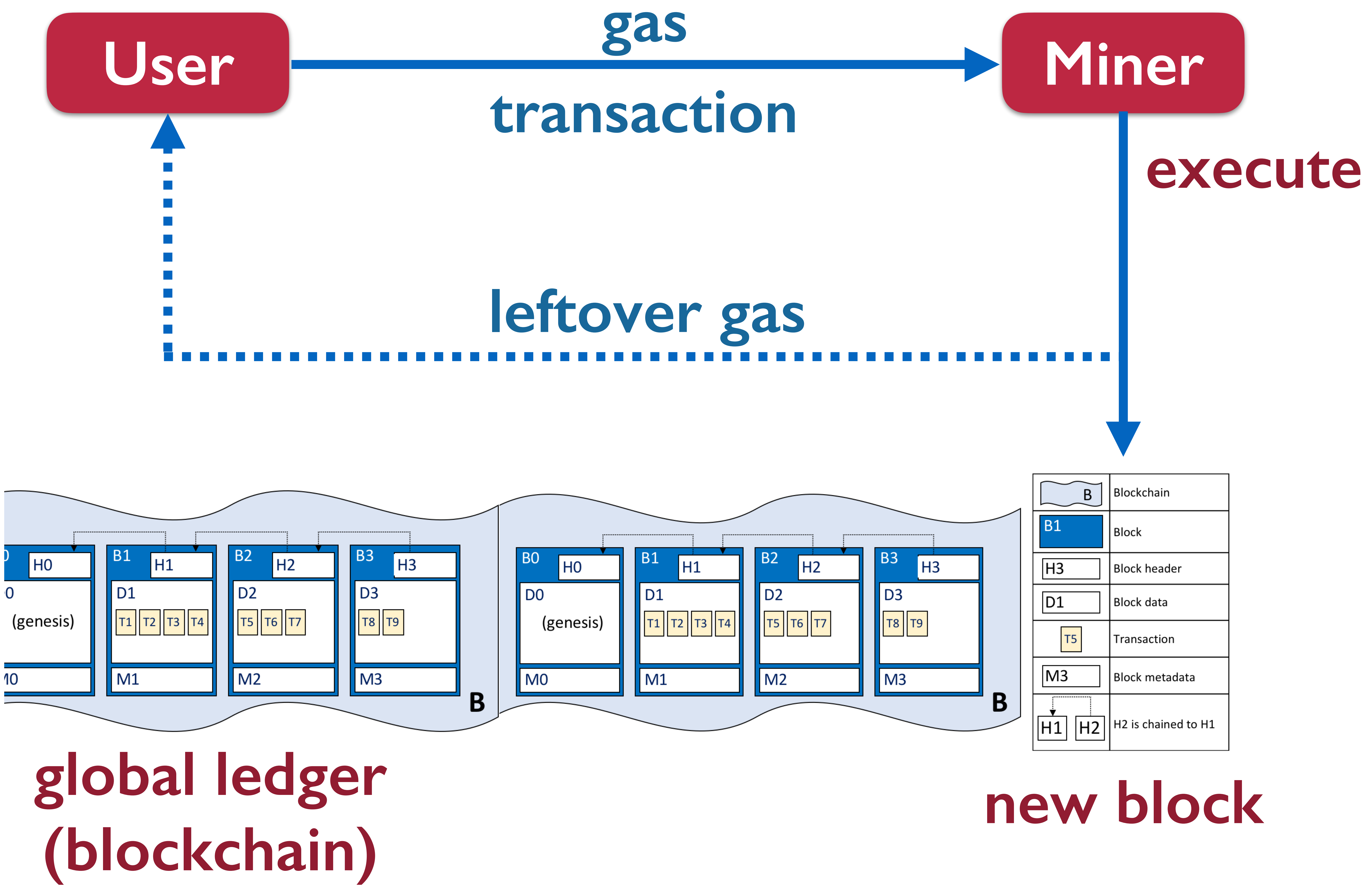

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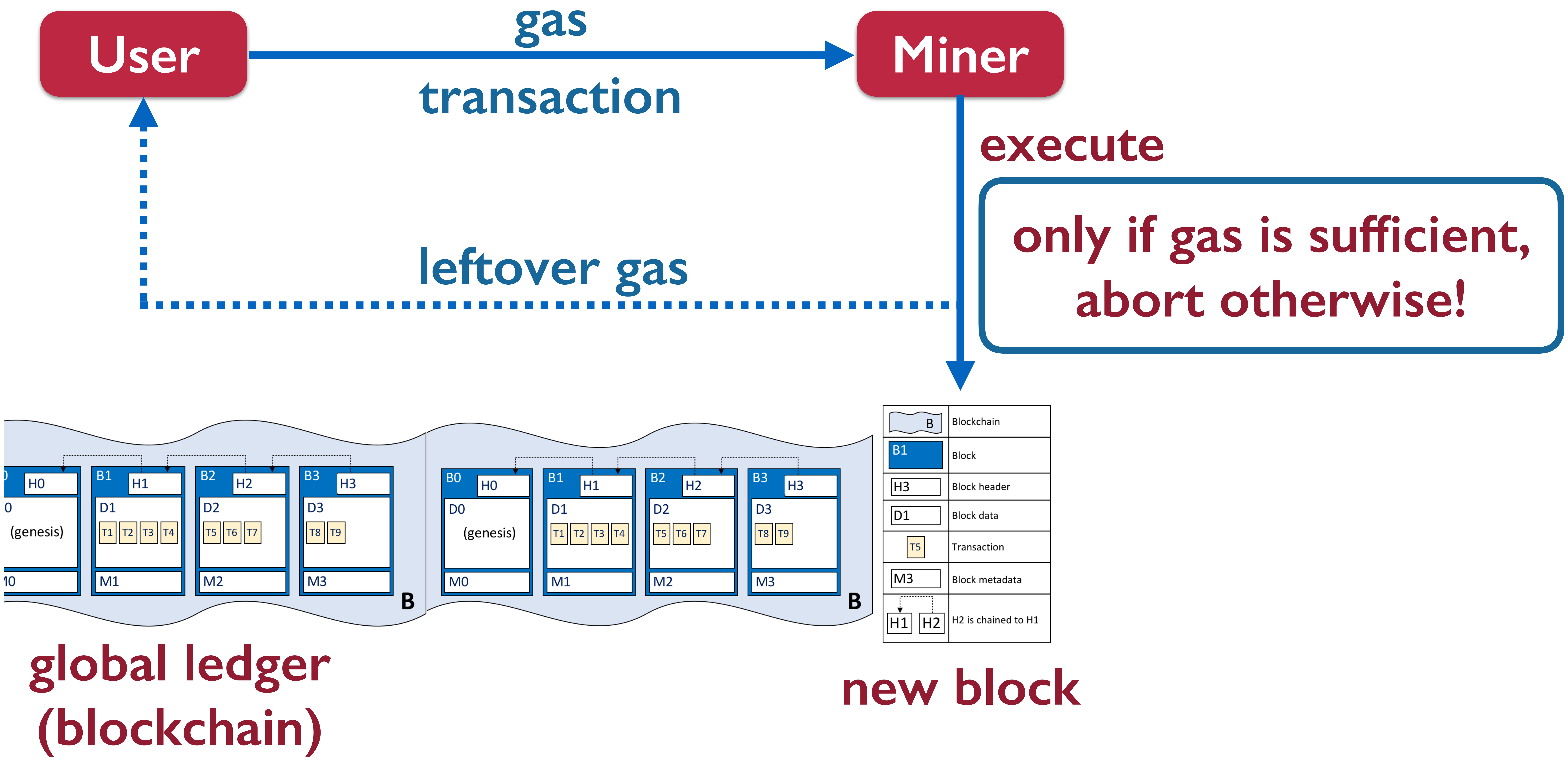

Prior Work on Gas Analysis

- Many tools for computing upper bound on gas cost statically (Gastap, Gasol, Nomos, etc.)
- Upper gas bounds are inadequate
  - Blockchains still track gas dynamically to return leftover gas, *creates runtime overhead*
  - Miners fit transactions in a block based on *exact gas cost*
- Need for *exact gas-cost analysis*
- Analysis should be *efficient*, otherwise can cause *DoS attacks*

Our Work — GasBoX

- GasBoX tool computes *exact* gas bound *statically* and *automatically* (relies on LP solver)
- Infers *constant* gas bounds in *linear-time*
- *Eliminates dynamic gas tracking*, compensates runtime overhead
- *Hoare-logic* style reasoning with an abstract notion of gas tank

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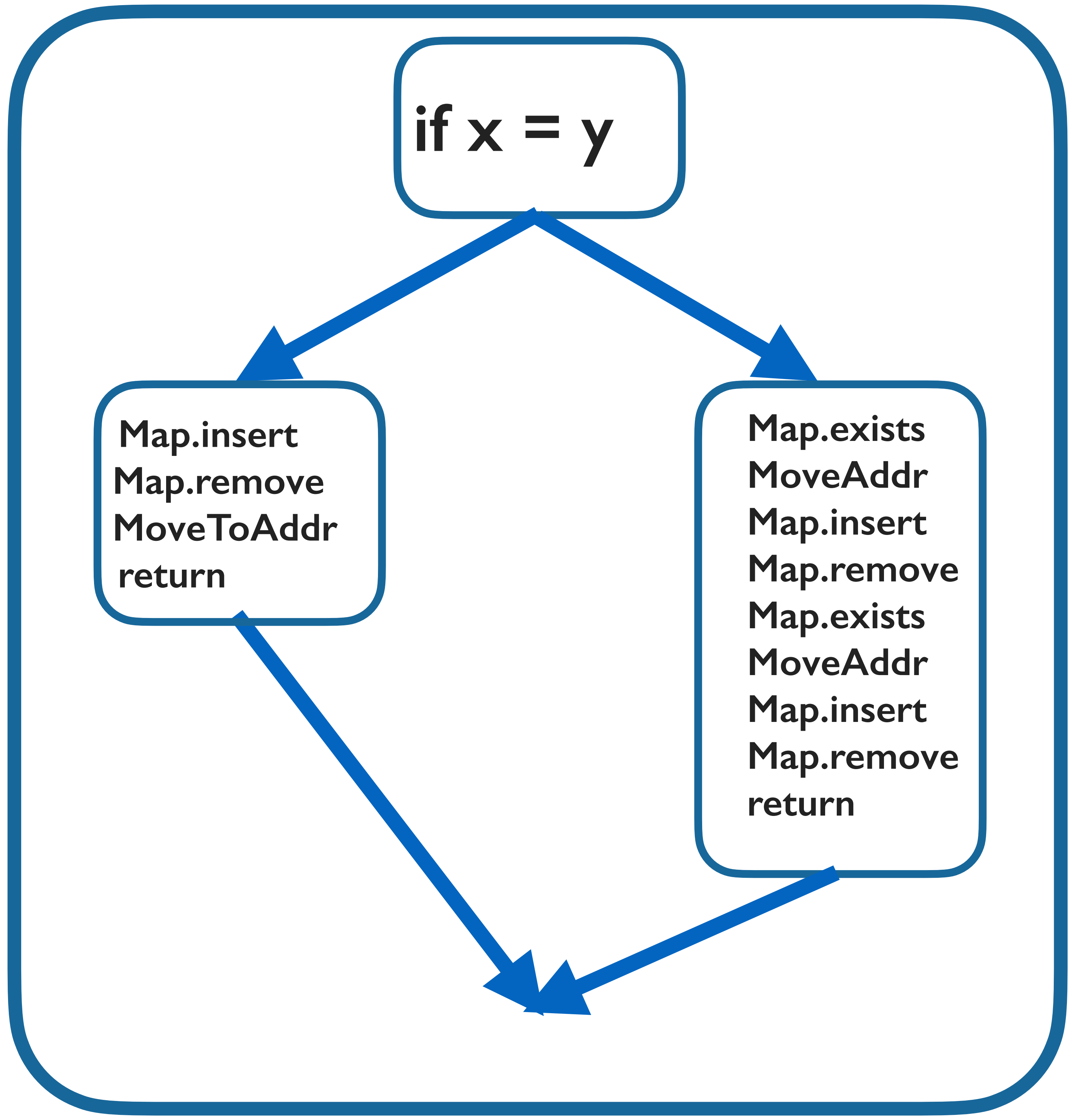
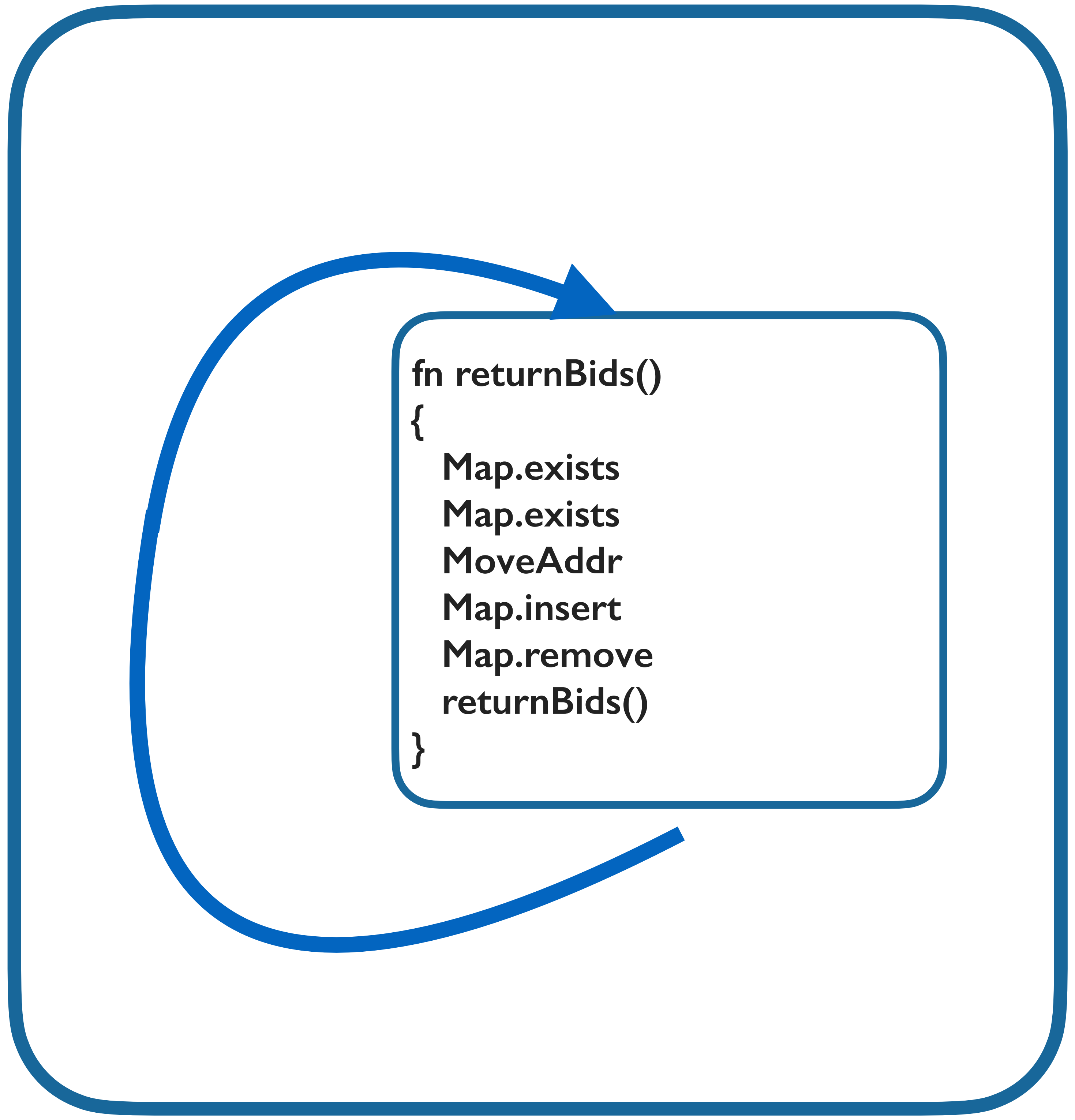
$$\{tank = \phi + \mathcal{C}(e)\}\ e\ \{tank = \phi \mid \phi \geq 0\}$$

$\mathcal{C}$(e): cost of executing expression e

Challenges





Exact gas bound in the presence of branches

Constant gas bound in the presence of recursion

Bidding in an Auction


```
fn addBid(bidmap: &Map<addr, Coin>, bidder: addr, bid: Coin)
{
  if Map.exists(bidmap, bidder)
  then
    tick(CMoveToAddr);
    MoveToAddr(bidder, bid);
  else
    tick(CMapInsert);
    Map.insert(bidmap, bidder, bid);
}
```

tick simulates a cost model

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cost of then branch:
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cost of else branch:
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cost of then branch: CMoveToAddr

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cost of else branch: CMapInsert

Cannot determine exact gas cost statically!

Gas.deposit operation


```
fn addBid(bidmap: &Map<addr, Coin>, bidder: addr, bid: Coin)
{
  if Map.exists(bidmap, bidder)
  then
    tick(CMoveToAddr);
    Gas.deposit(CMapInsert);
    MoveToAddr(bidder, bid);
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    tick(CMapInsert);
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deposits the corresponding gas units in sender' account

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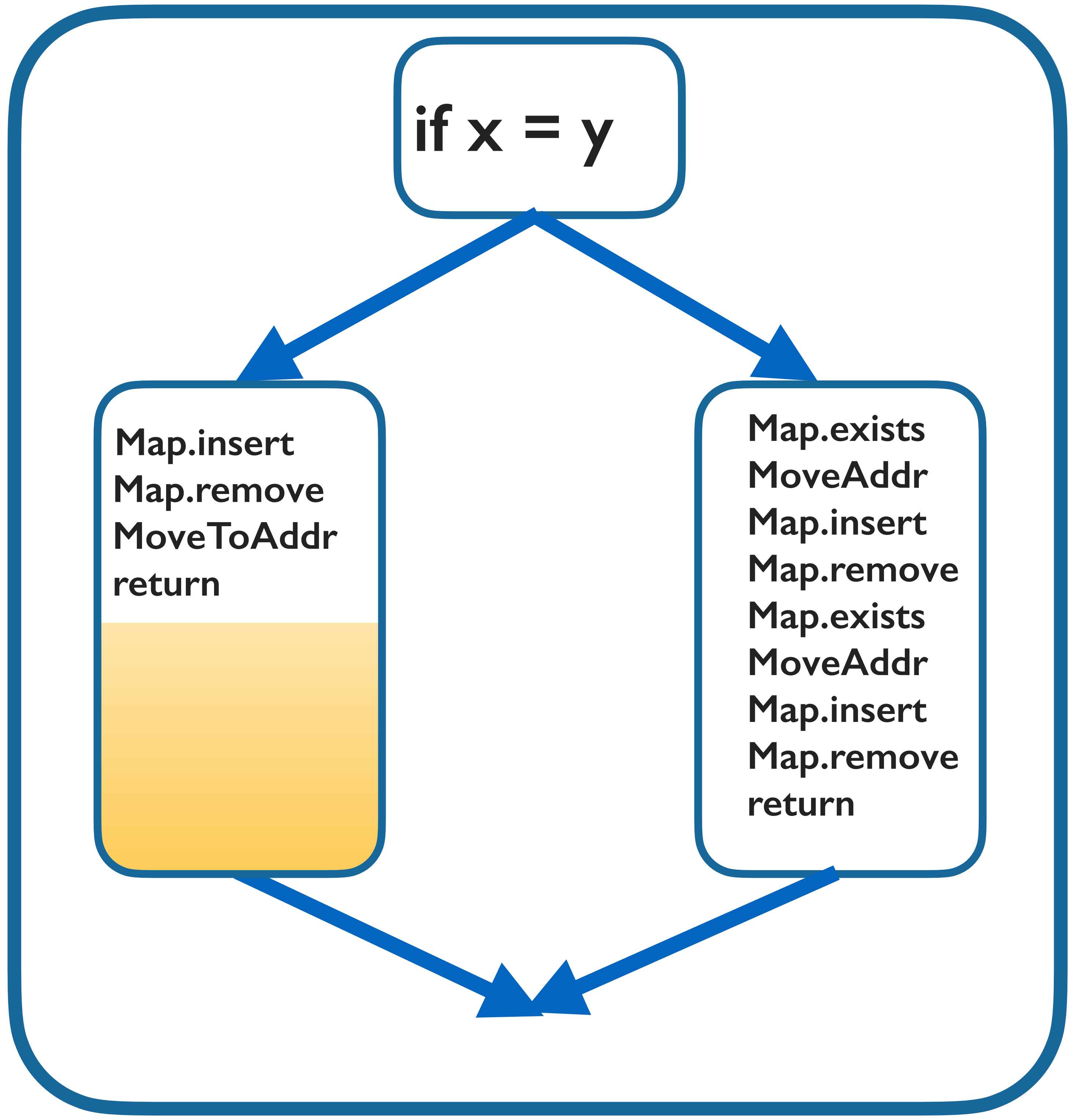
cost of then branch: CMoveToAddr + CMapInsert

=

cost of else branch: CMapInsert + CMoveToAddr

Advantages of Gas.deposit



Less costly branch augmented with Gas.deposit

- Returns leftover gas to sender of transaction
- *Eliminates* dynamic gas metering
- GasBox inserts deposit operations *automatically*
- *No burden* on the programmer

Handling Unbounded Computation


```
fn returnBids(bidmap : &Map<addr, Coin>)
{
  if Map.size(bidmap) > 0
  then
    let (bidder, bid) = Map.remove_first(bidmap);
    tick(CMoveToAddr);
    MoveToAddr(bidder, bid);
    returnBids(bidmap);
}
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cost of returnBids =

CMoveToAddr * *sizeof* (bidmap)

Gas cost is not a constant, depends on argument size!

Gas Amortization


```
resource GasBid
{
  gas : Gas(CMoveToAddr),
  bid : Coin
}

fn addBid(bidmap: &Map<addr, GasBid>, bidder: addr, b: Coin)
{
  if Map.exists(bidmap, bidder)
  then
    tick(CMoveToAddr);
    MoveToAddr(bidder, b);
    Gas.deposit(CMapInsert + CMoveToAddr);
  else
    let g = Gas.construct(CMoveToAddr);
    let gbid = pack<GasBid> {gas: g, bid: b};
    tick(CMapInsert);
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store CMoveToAddr gas units inside a bid

cost of addBid =

2 * CMoveToAddr + CMapInsert

Stored Gas pays for Recursion


```
fn returnBids(bidmap : &Map<addr, GasBid>)
{
  if (Map.size(bidmap) > 0)
  then
    let (bidder, gbid) = Map.remove_first(bidmap);
    let (g, bid) = unpack<GasBid>(gbid);
    Gas.destruct(g);
    tick(CMoveToAddr);
    MoveToAddr(bidder, bid);
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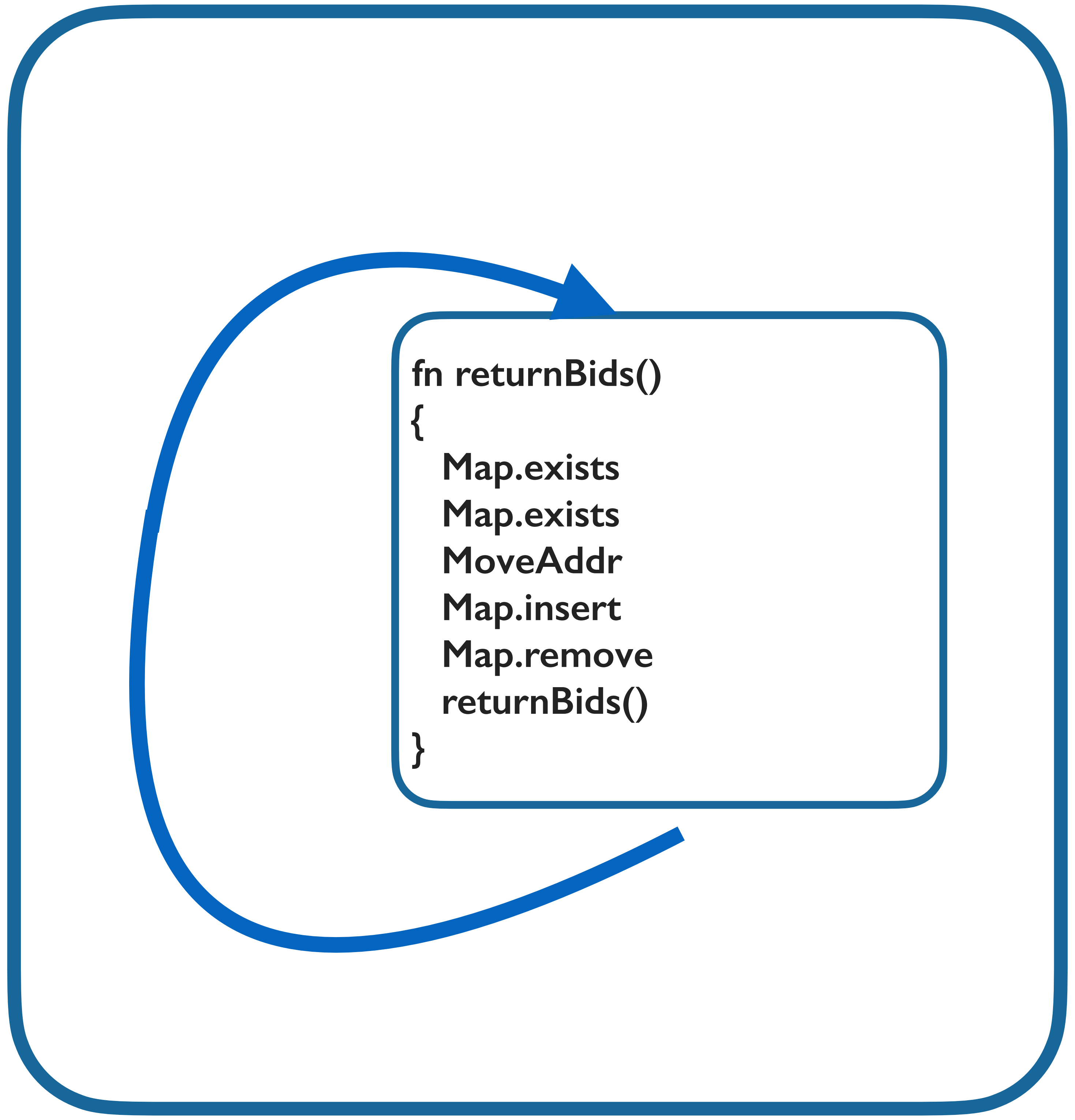
destruct the gas to pay for ticks

cost of returnBids = 0

Advantages of Gas Amortization



Gas amortization pays for the cost of recursion

- *Simplifies* analysis (no need to track sizes of data structures)
- Gas bound of returnBids *cannot exceed block gas limit*
- *Equitable gas-distribution:* bidder pays for the gas cost of return of their bid
- *Constant gas bound* even though unbounded gas cost!

Inference of Gas Bounds


```
resource GasBid
{
  gas : Gas(*),
  bid : Coin
}
```

```
resource GasBid
{
  gas : Gas(CMoveToAddr),
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```

- GasBoX *infers gas bounds of all functions* in the program
- Also infers the gas to be *stored inside data structures*
- Programmers only need to *indicate where gas needs to be stored*
- Low programmer burden!

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Formal Analysis

$$\{tank = \phi + \mathcal{C}(e)\}\ e\ \{tank = \phi \mid \phi \geq 0\}$$

$$\{tank = \phi + n\}\ \texttt{tick}(n)\ \{tank = \phi \mid \phi \geq 0\}$$

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$$\{tank = \phi \mid v : \texttt{Gas}(n)\}\ \texttt{Gas.destruct}(v)\ \{tank = \phi + n\}$$

$$\{tank = \phi + \mathcal{C}(e)\}\ \texttt{return}\ e\ \{tank = \phi \mid \phi = 0\}$$

Formal Analysis

$$\{tank = \phi + \mathcal{C}(e)\}\ e\ \{tank = \phi \mid \phi \geq 0\}$$

tick, Gas.deposit and Gas.construct remove n units from tank

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Gas.destruct adds n units to tank

post-gas after return must be 0

Soundness Theorem

If $\{tank = \phi\}\ e\ \{tank = \phi'\}$,

and $e \Downarrow^{\mu}_{\mu'} v$,

then $\phi - \phi' = \mu - \mu'$.

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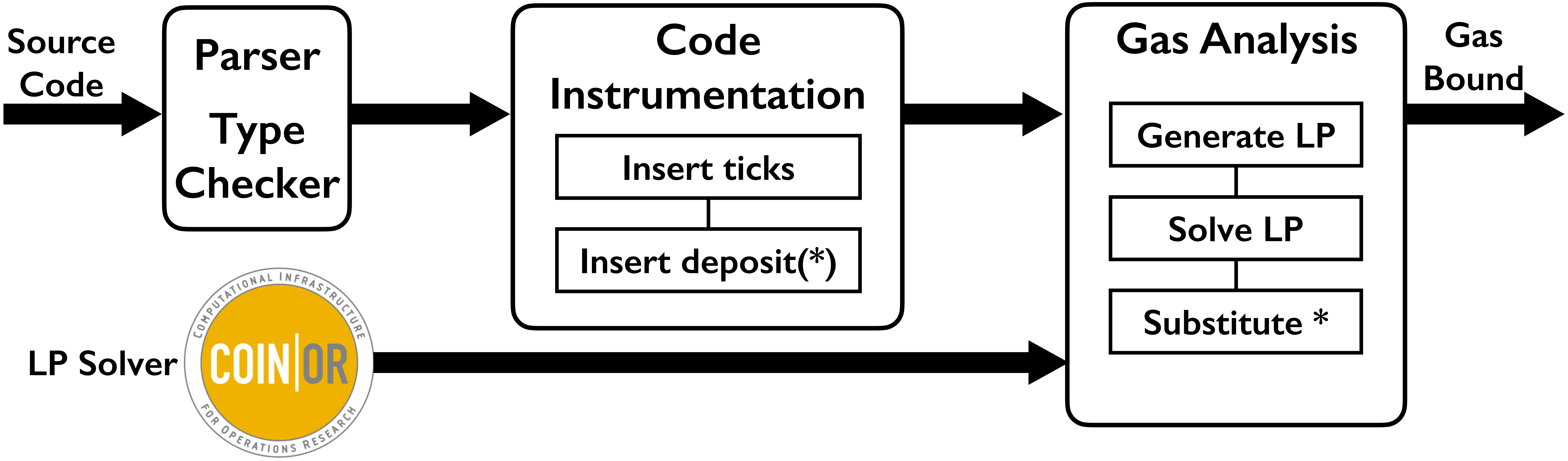
Static Gas Cost

Dynamic Gas Cost

Workflow of GasBoX



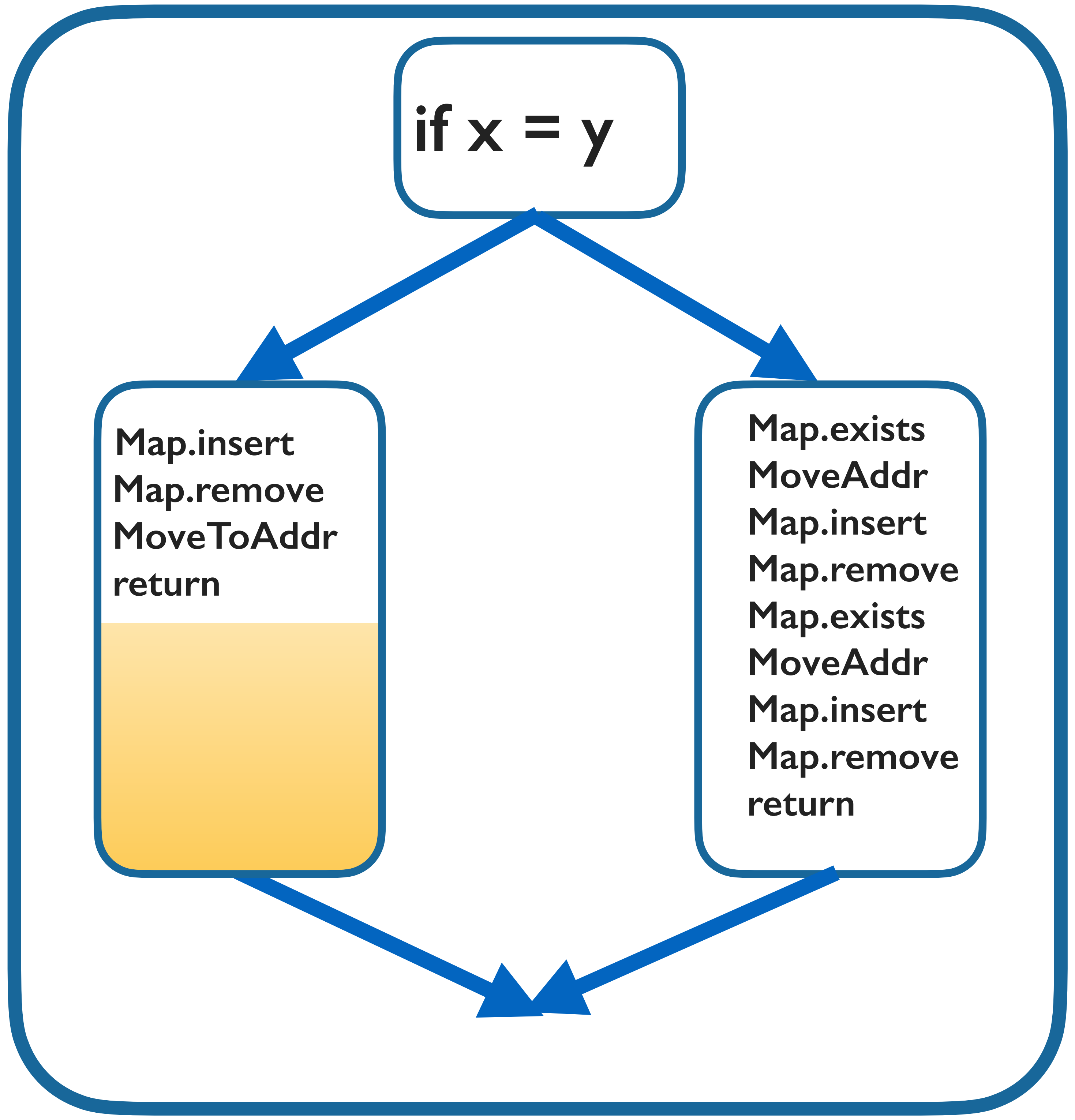
- ticks and deposits are automatically inserted by GasBoX
- relies on type checker and LP solver for inferring bounds

Evaluation

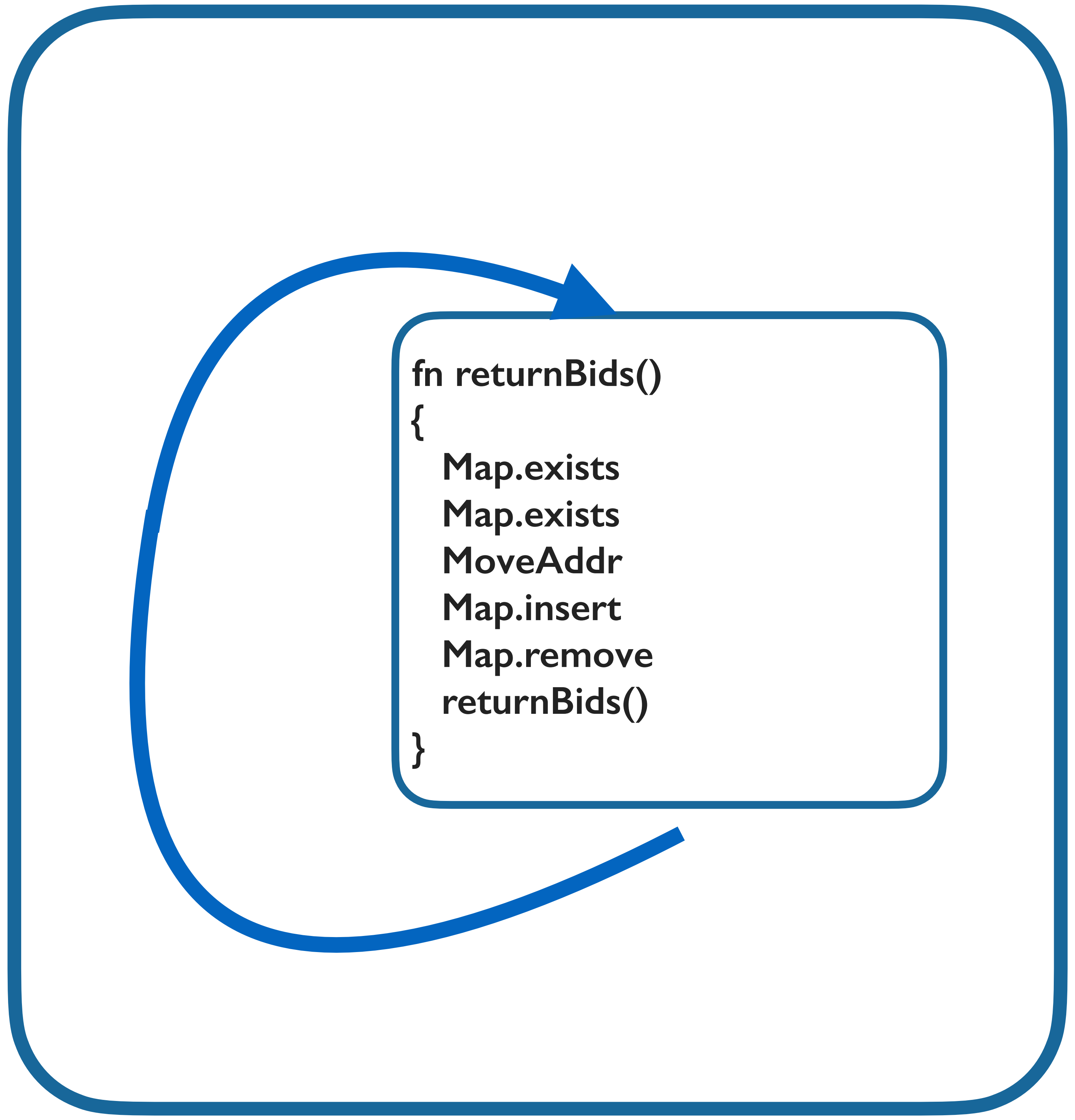
Contract	LOC	Defs	Vars	Cons	I (ms)	V (μs)
auction	44	7	3	44	3.05	12.16
bank	138	14	11	254	3.97	54.12
ERC 20	101	11	8	191	3.45	56.98
escrow	140	7	9	213	3.29	61.03
insurance	43	5	3	43	3.02	9.05
voting	75	7	8	131	3.19	30.99
wallet	74	8	5	158	3.35	52.93
ethereumpot	259	13	13	332	3.94	101.08
puzzle	62	6	6	91	3.13	15.97
amort. auction	70	7	5	62	2.99	15.02
amort. bank	189	17	17	347	4.44	73.19
tether	382	29	30	842	26.14	365.01
libra system	124	12	12	170	3.38	45.06
Total	**1701**	**143**	**130**	**2878**	**67.34**	**892.59**

- LOC: lines of code
- Defs: functions
- Vars, Cons: variables and constraints in LP
- I (ms): inference time in milliseconds
- V(us): verification time in microseconds

Conclusion



Less costly branch augmented with Gas.deposit



Gas amortization pays for the cost of recursion

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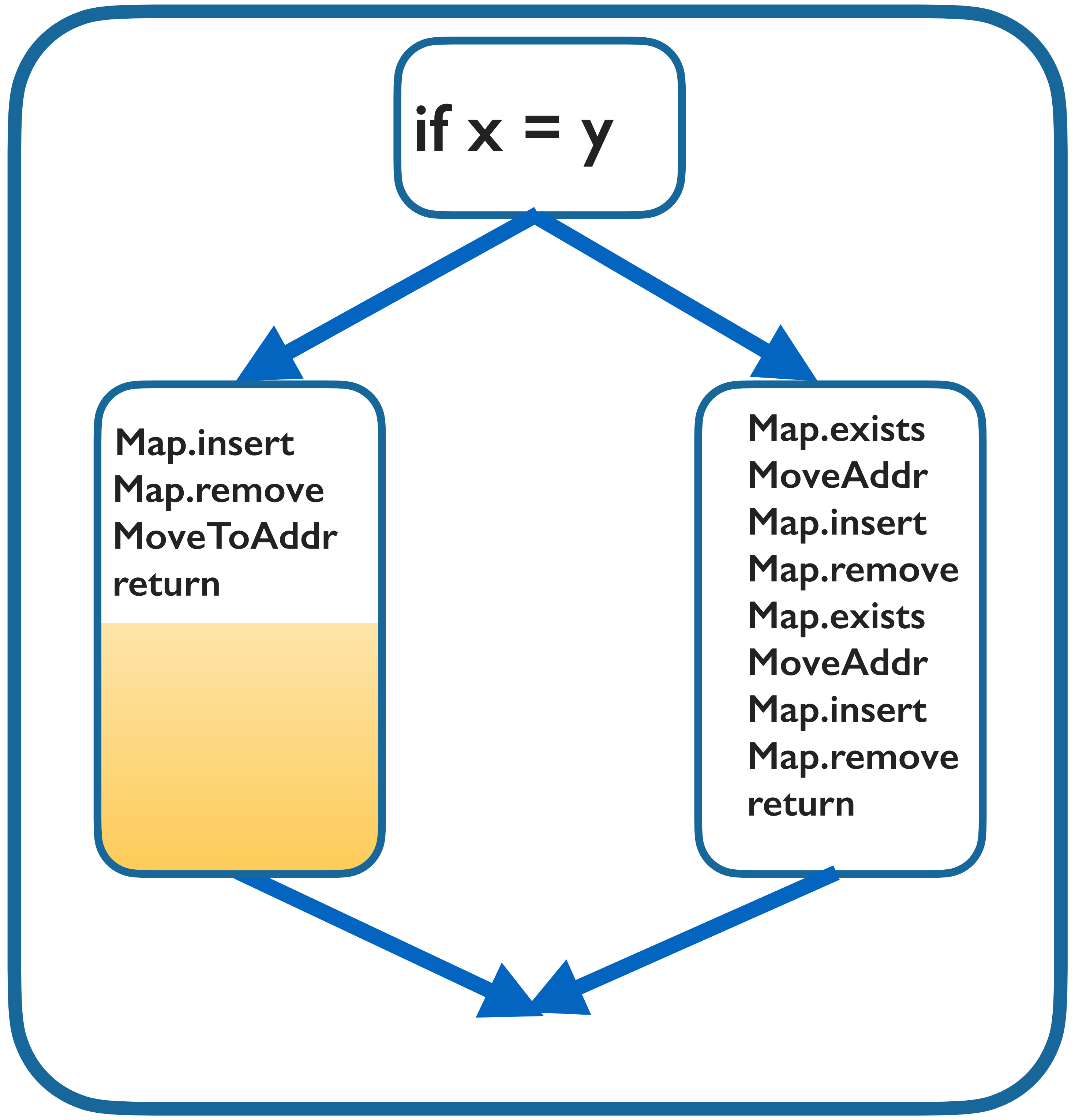
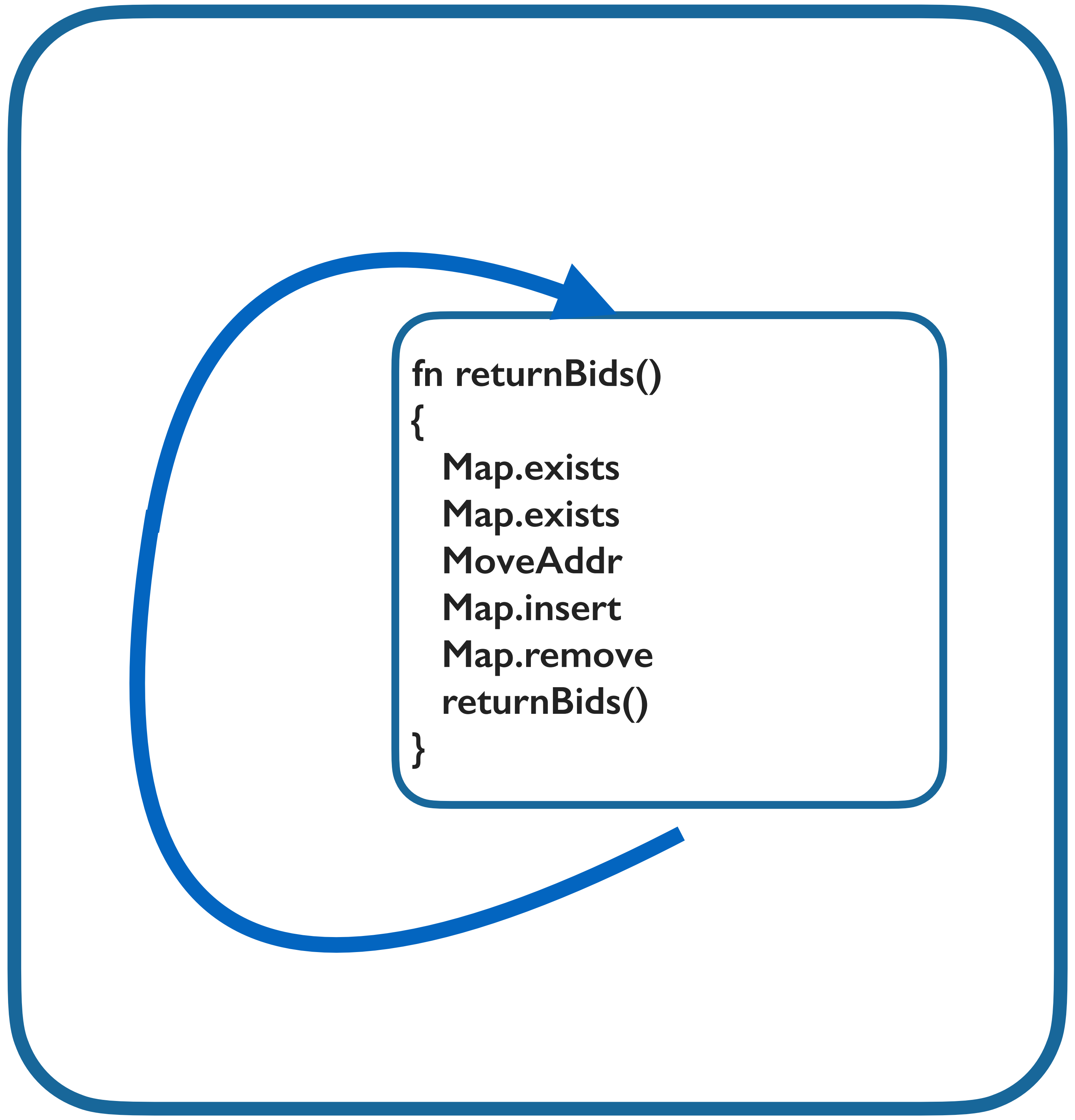


Hoare-logic style gas-analysis framework



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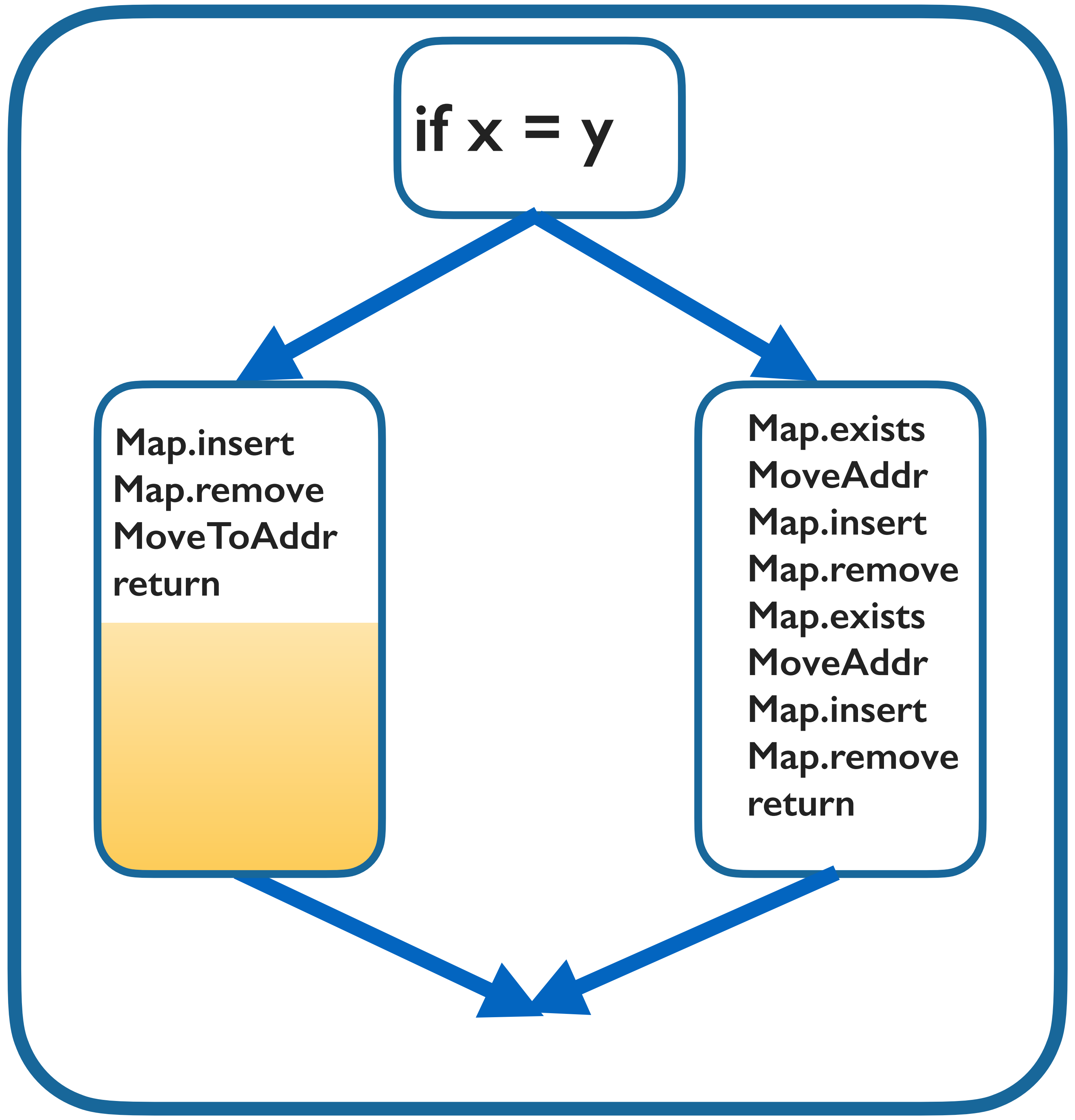
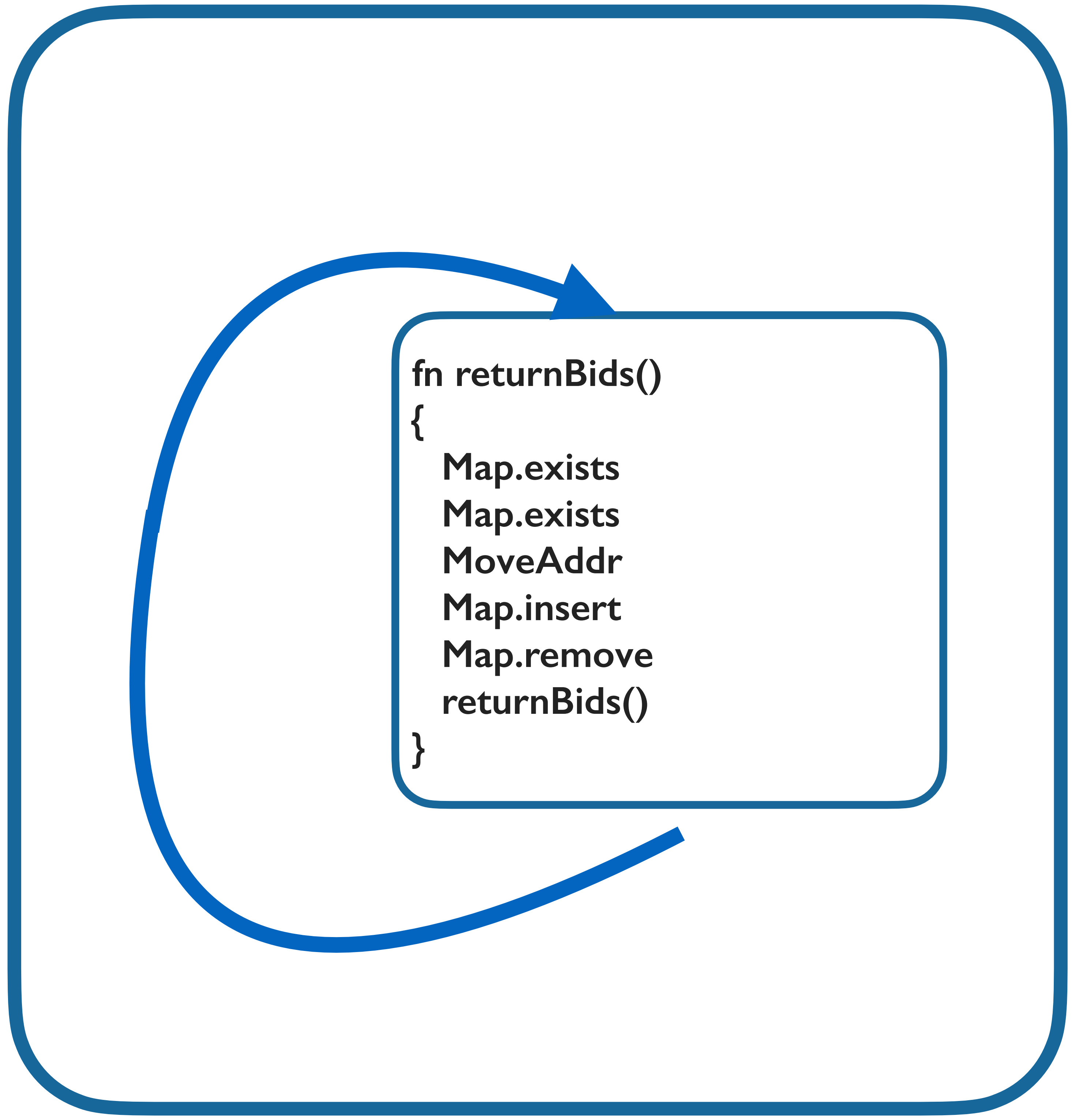


Hoare-logic style gas-analysis framework

inference of exact gas bounds in linear-time



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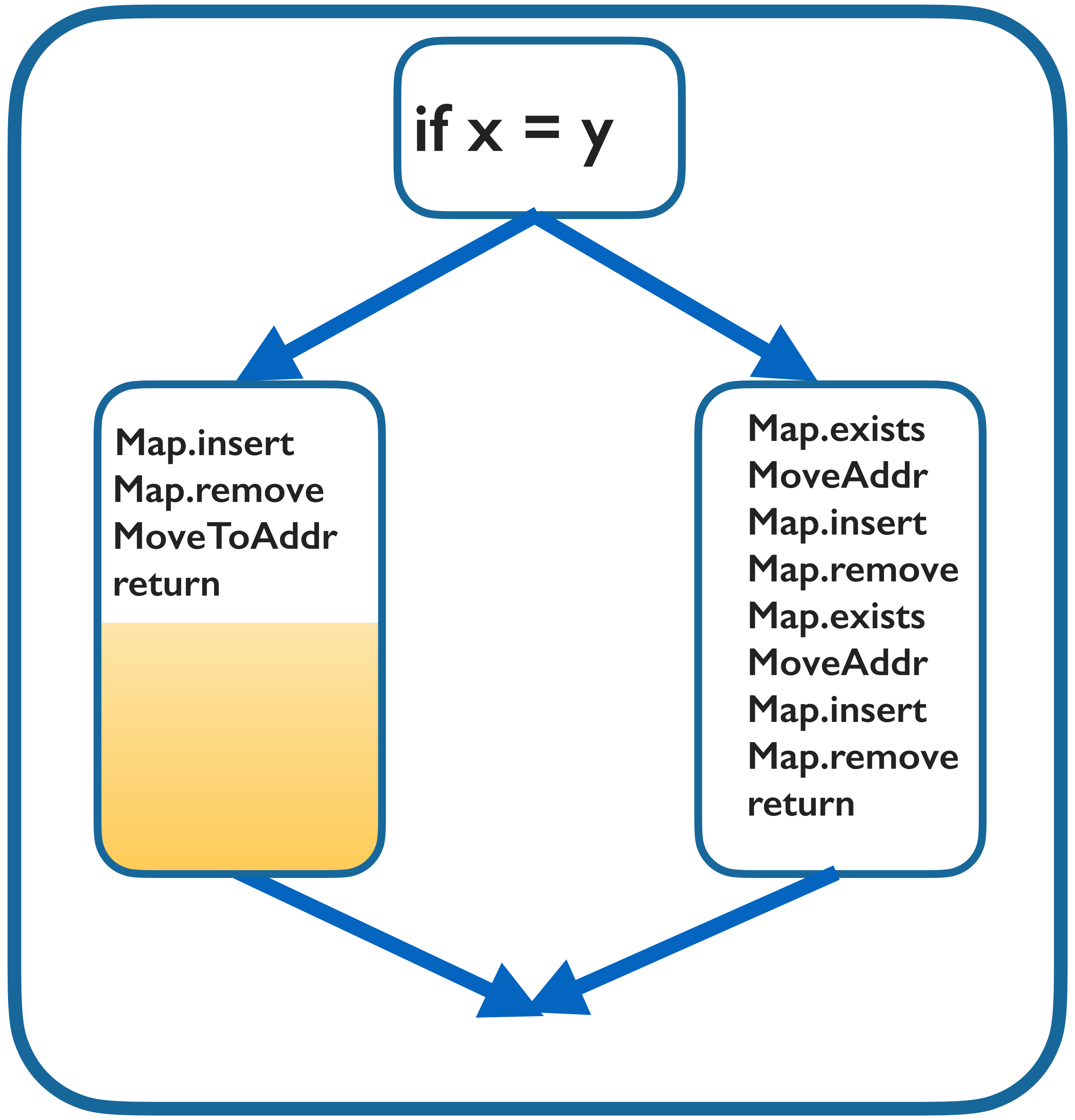
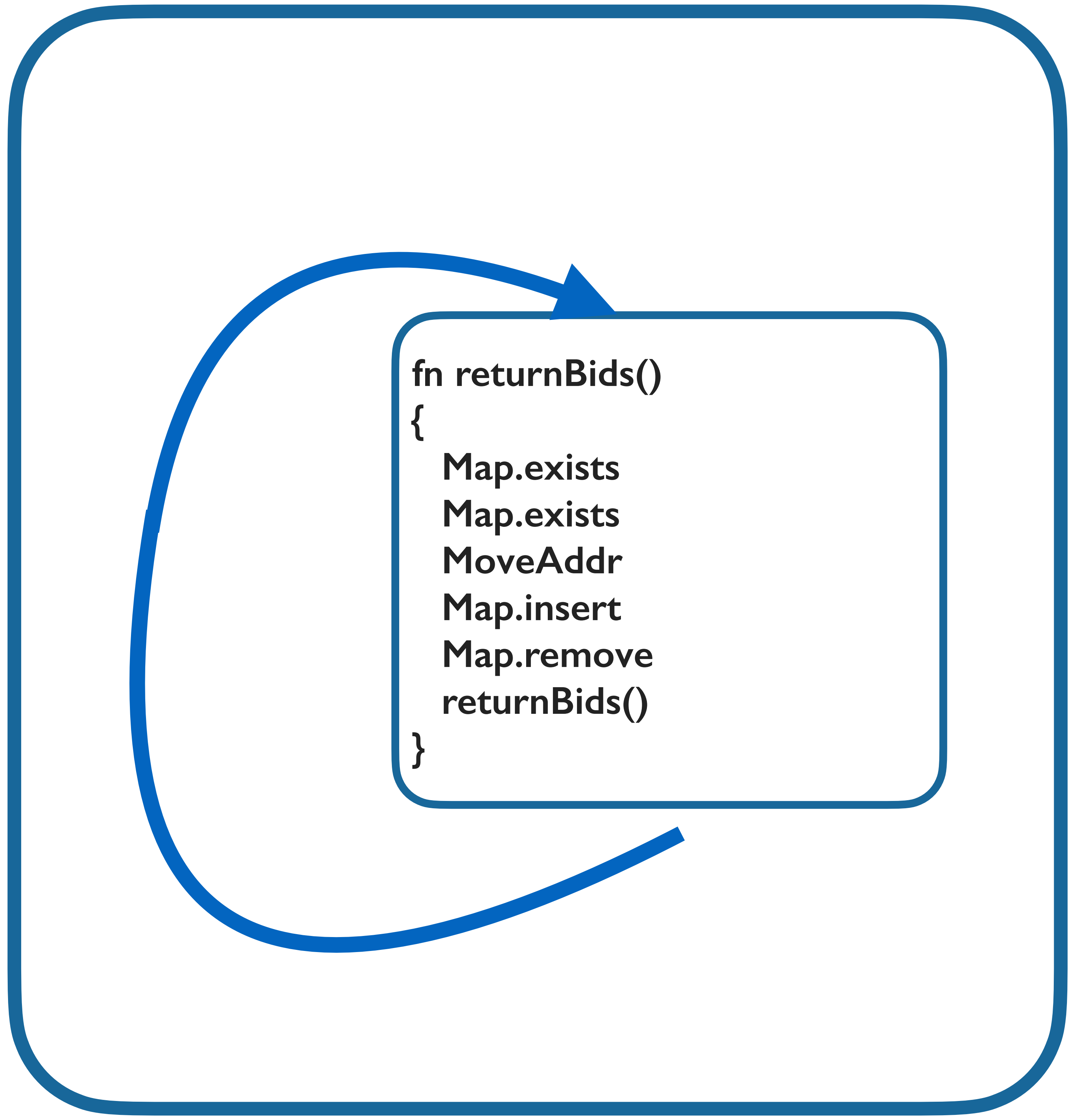


Less costly branch augmented with Gas.deposit

Hoare-logic style gas-analysis framework

inference of exact gas bounds in linear-time

low programmer burden
no gas tracking



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