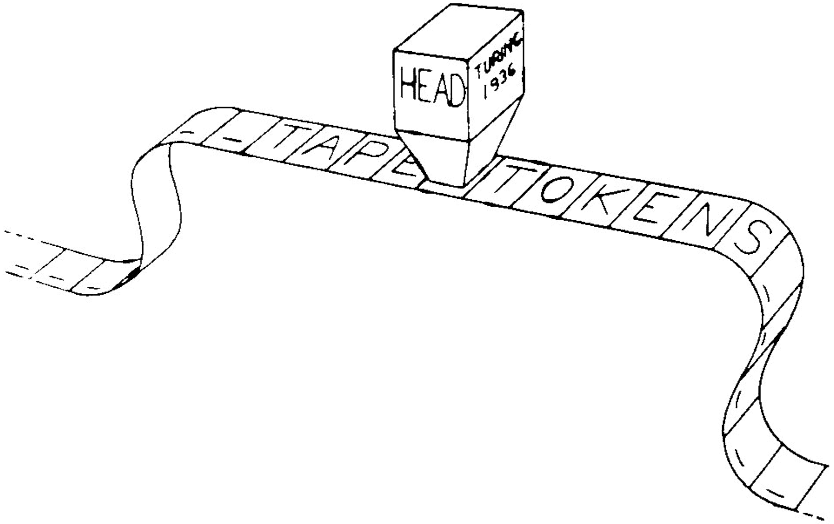
Classical Universality: Turing

Universality of Consensus [Lamport-Schneider-Herlihy-CT]



Linearizable
(atomic)

Highly-available
(wait-free)

Act1: Universality

Turing

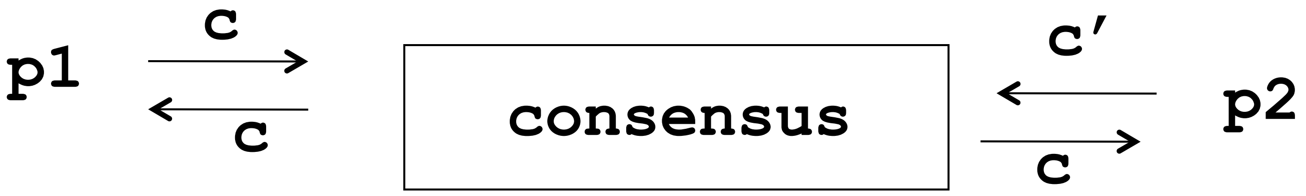
Act 2: Modern Universality

Turing + Lamport

Consensus

Processes propose each a value and ***agree*** on one

output = ***propose(***input***)***



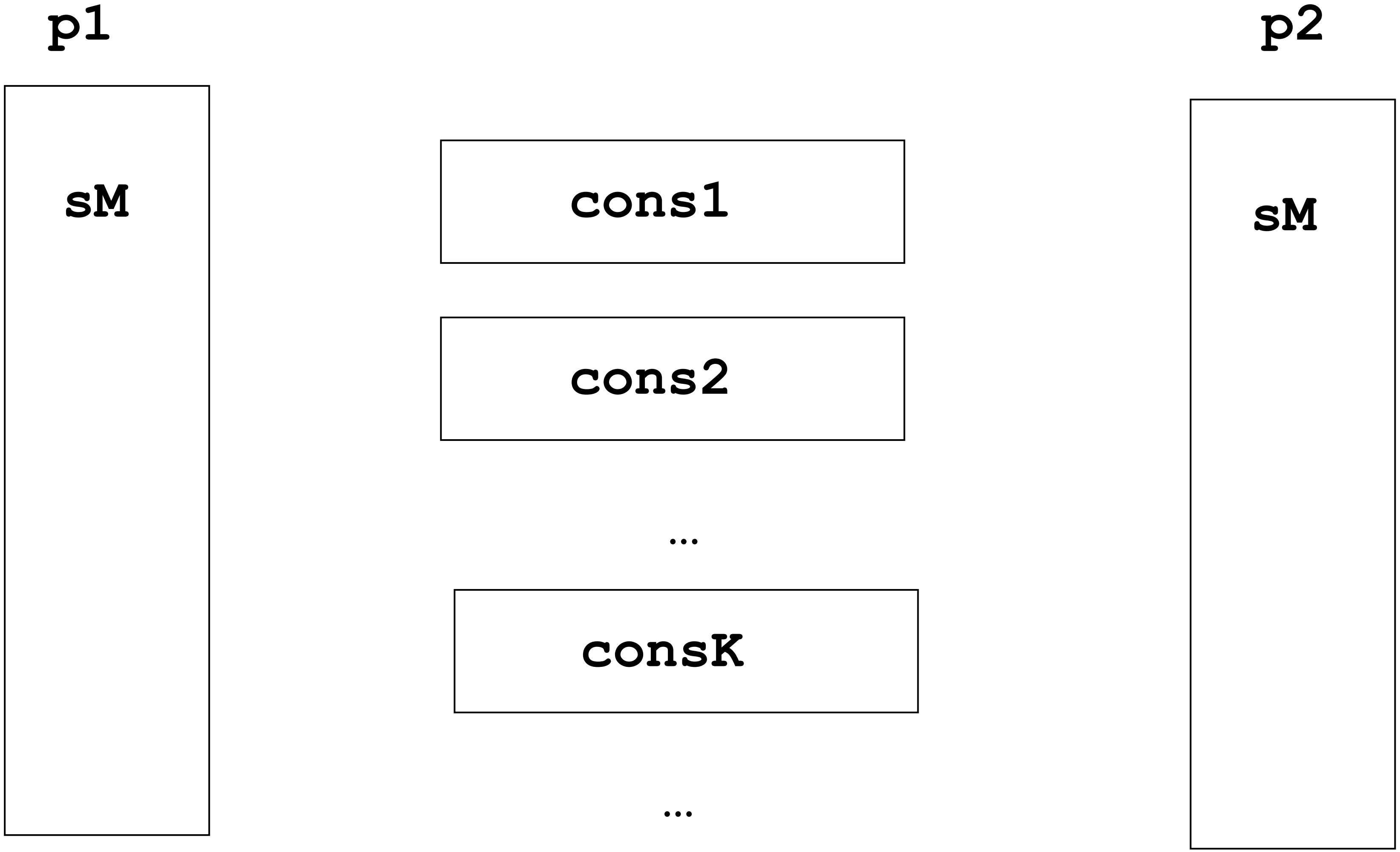
Universal Construction

Each process holds a copy of the simulated machine

Each process holds a list of commands for the machine

All processes share a list of consensus objects

Universal Construction



p1

sM

cons1

cons2

...

consK

...

p2

sM

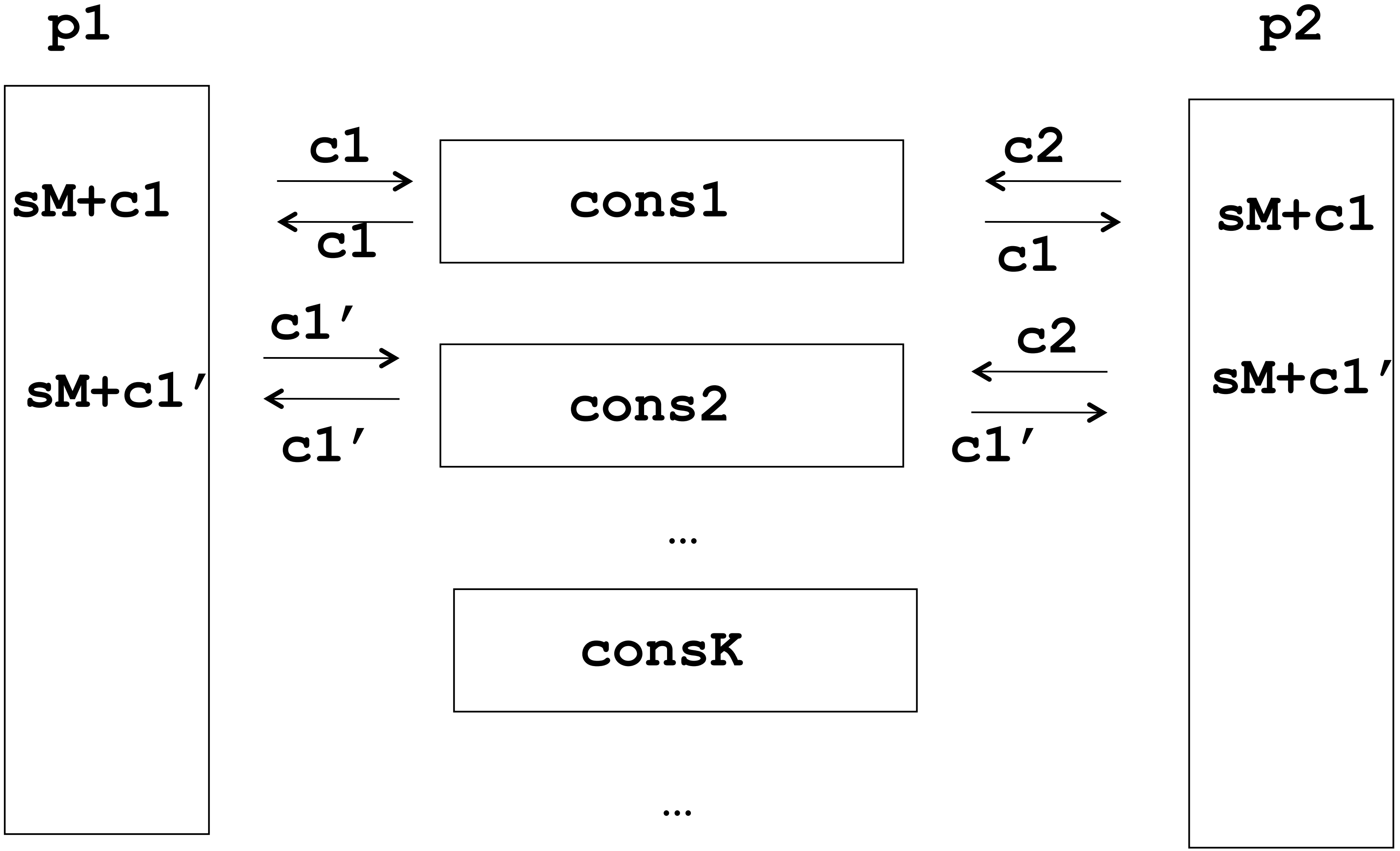
Universal Construction

- while(true)

- c = commands.next()
- cons = Consensus.next()

- c’ = cons.***propose***(c)
- sM.***perform***(c’)

Universal Construction



What if consensus is not ensured?

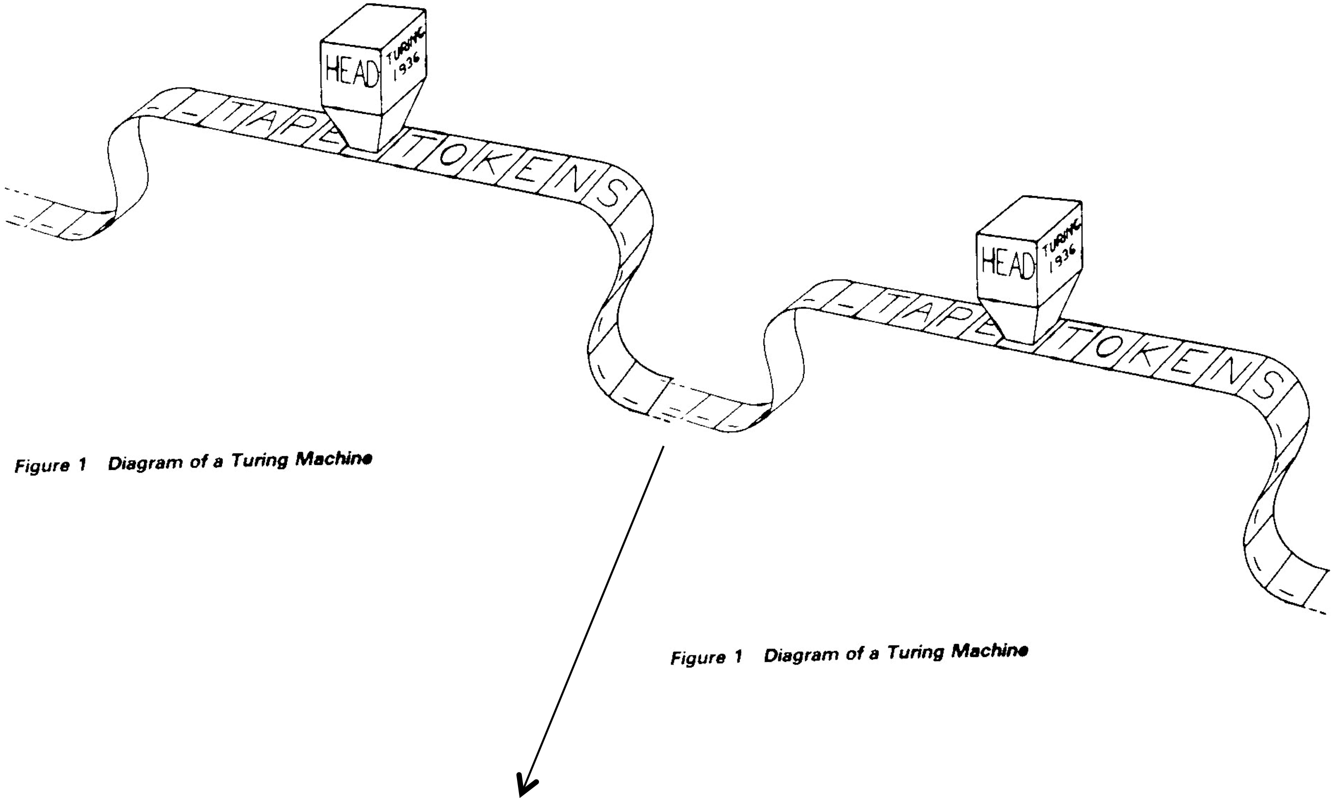


Figure 1 Diagram of a Turing Machine

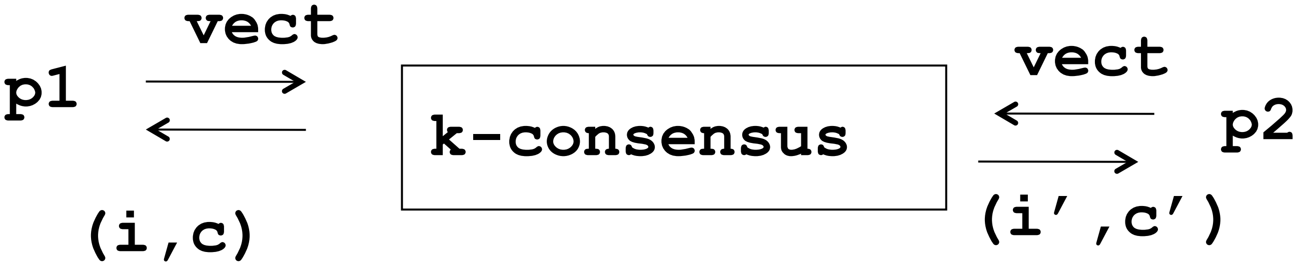
Figure 1 Diagram of a Turing Machine

Consensus

K-Consensus

Every process proposes a vector of k values and returns a value at some position (Chauduri et al)

(i,c) = ***propose(***kVect***)***



p1

vect

(i,c)

k-consensus

vect

p2

(i’,c’)

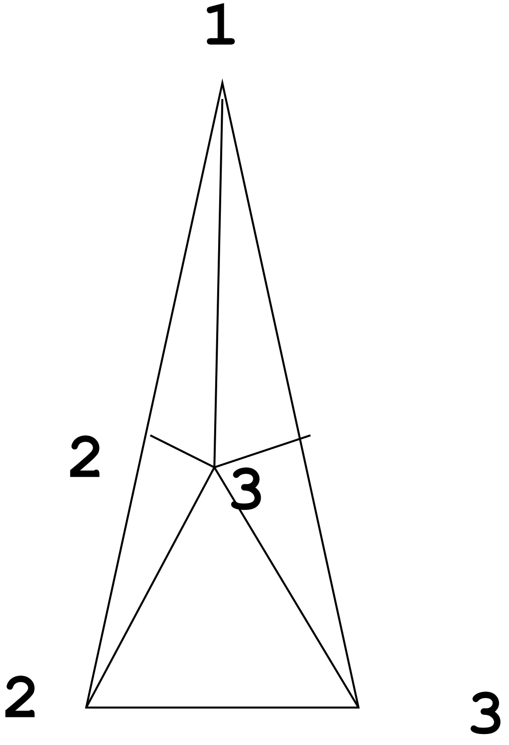
K-Consensus

- ***Validity***: the value returned at any position has been proposed at that position

- ***Agreement***: no two values returned at the same position are different

- ***Termination***: every correct process that proposes eventually returns k+1-consensus is strictly weaker than k-consensus in any system of more than k+1 processes

(Godel prize 2004 – HS,BG,SZ 93)

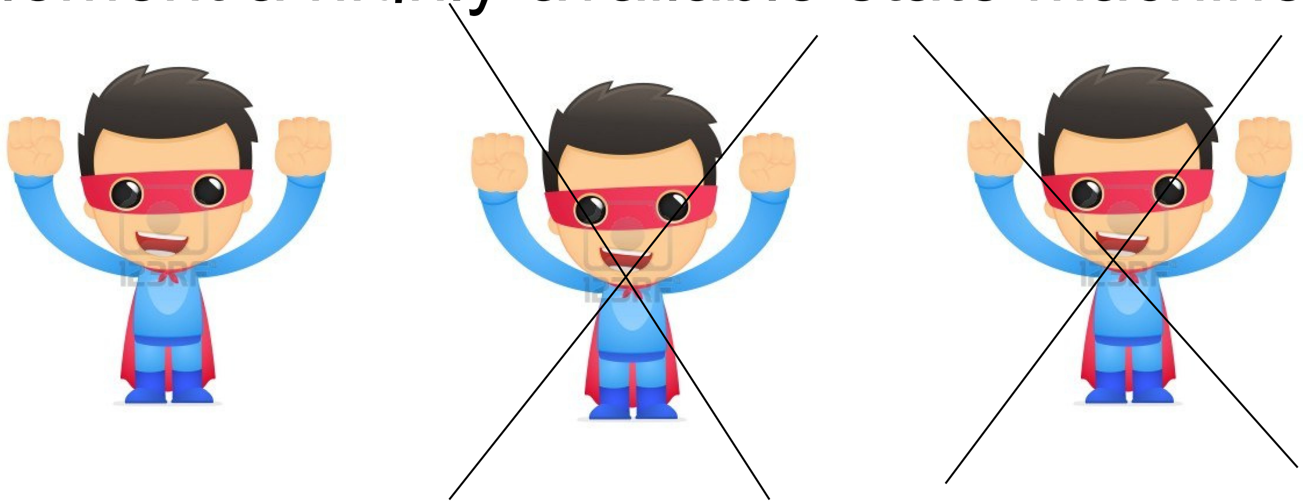


Sperner’s Lemma: at least one triangle has three colors

What form of universality with K-consensus?

With consensus

We implement a highly-available state machine



With k-consensus

We implement k state machines of which ***at least one*** is highly-available

Generalized Universality

Act1: Universality

Turing

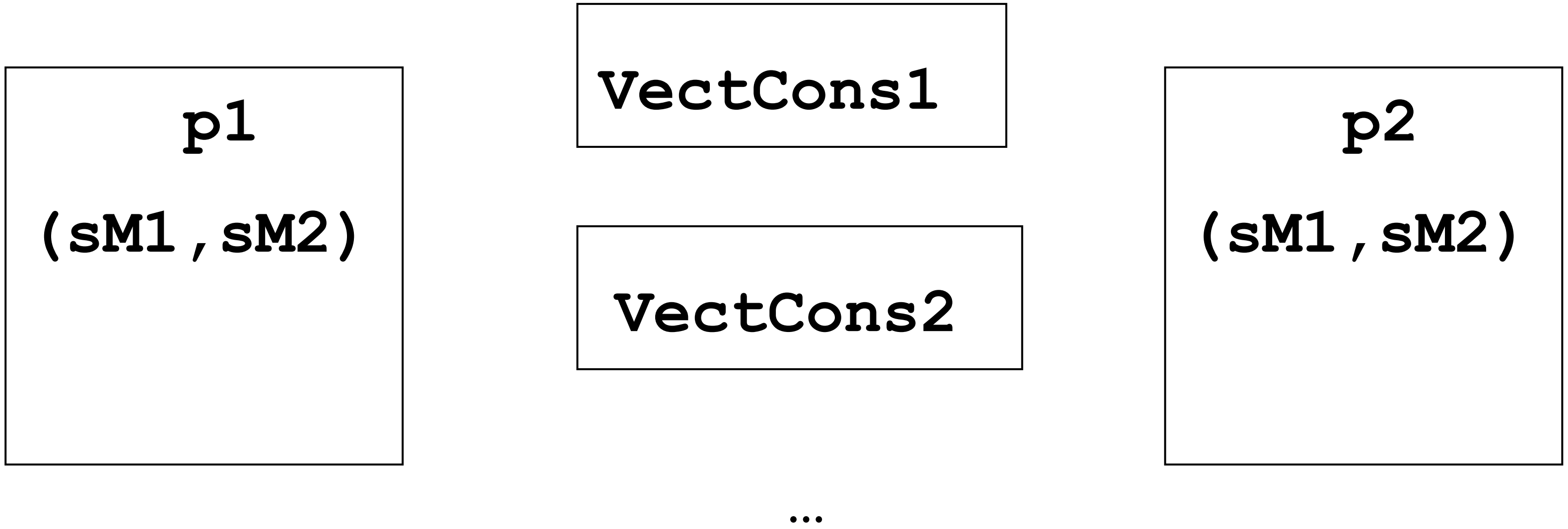
Act 2: Modern Universality

Turing + Lamport

Act 3: Generalized Universality

Generalized Universality

Each process holds a copy of each of the machines sM(i) - and a lists of commands for each



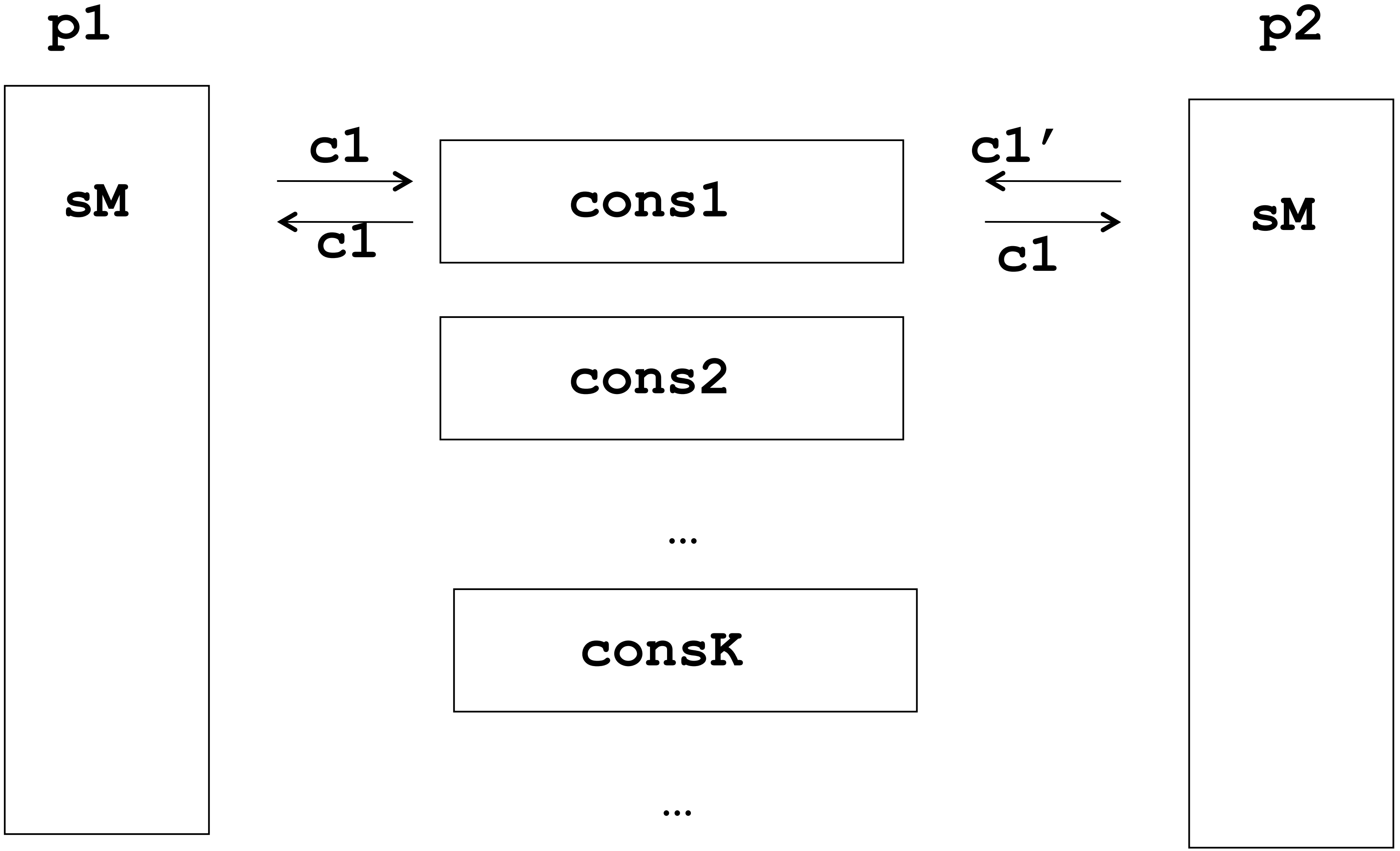
The processes share a list of k-vector consensus objects

Universal Construction

```
while(true)
    c = commands.next()
    cons = consensus.next()

    c’ = cons.propose(c)
    sM.perform(c’)
```

Universal Construction

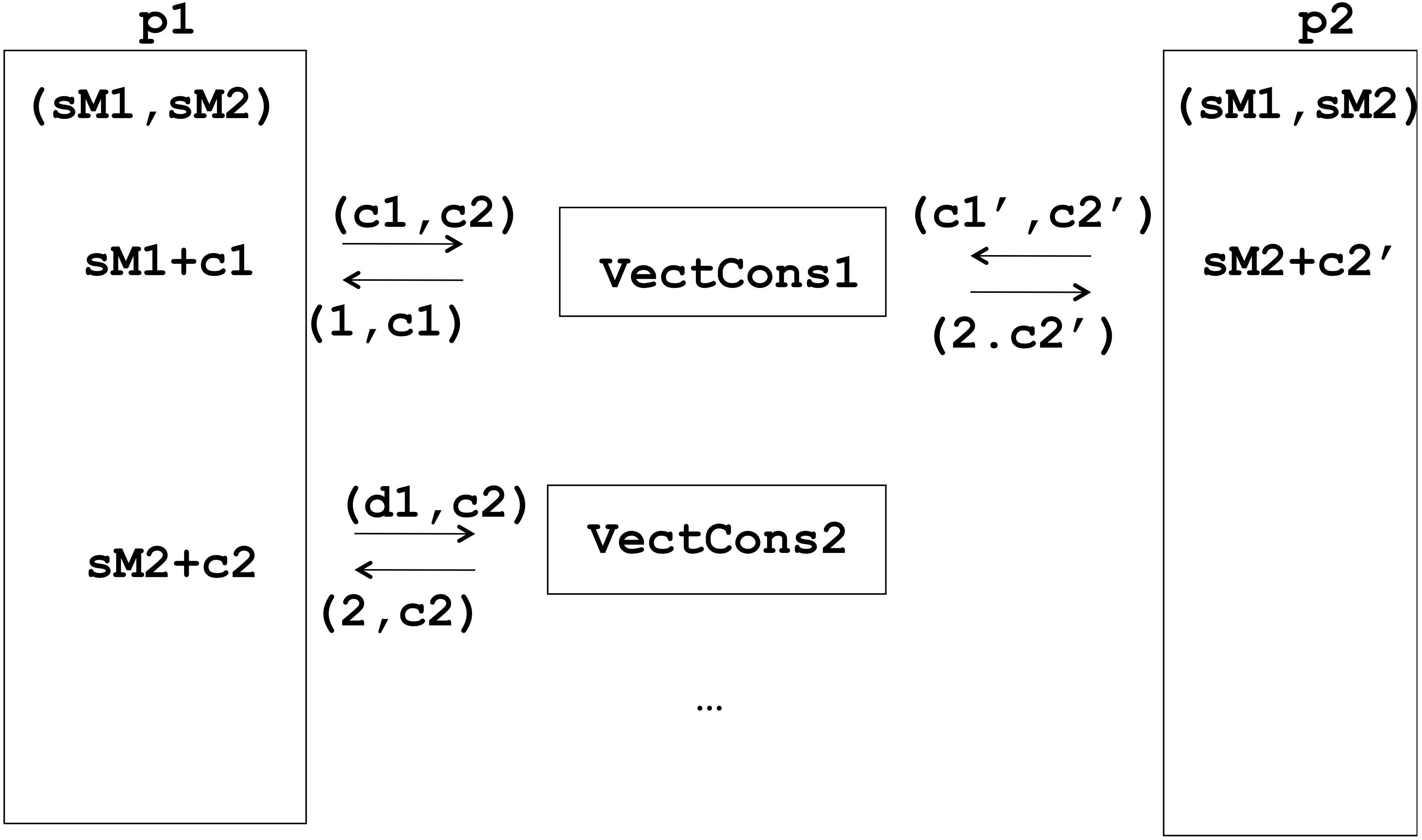


Generalized Universality?
Problem with safety

```
while(true)
    for j = 1 to k: com(j) = commands(j).next()
    kVectC = kVectCons.next()

    (c,i) = kVectC.propose(com)
    sM(i).perform(c)
```

Problem with safety



p1

(sM1,sM2)

sM1+c1

sM2+c2

(c1,c2)

(1,c1)

VectCons1

(d1,c2)

(2,c2)

VectCons2

…

(c1′,c2′)

(2.c2′)

p2

(sM1,sM2)

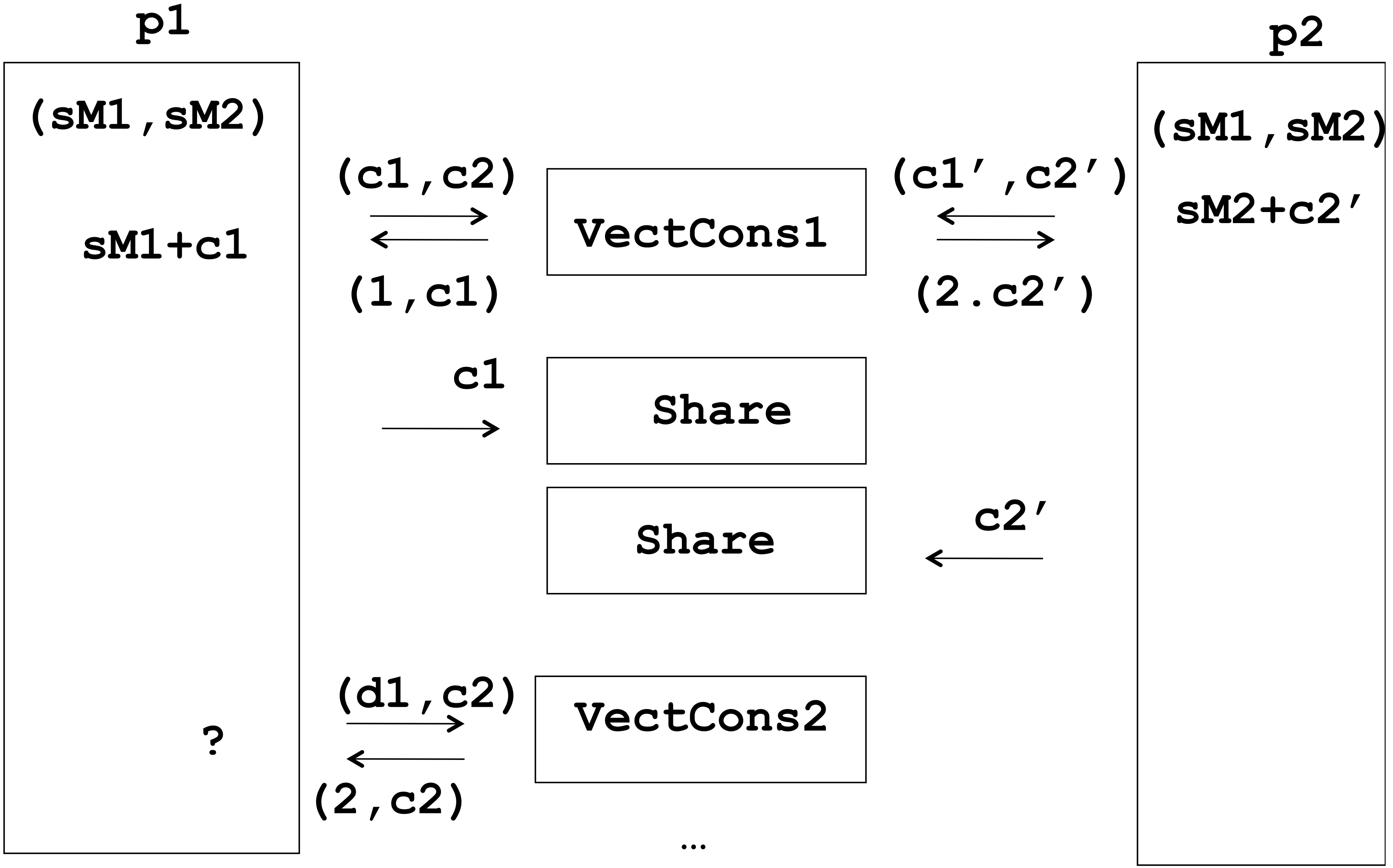
sM2+c2′

Generalized Universality

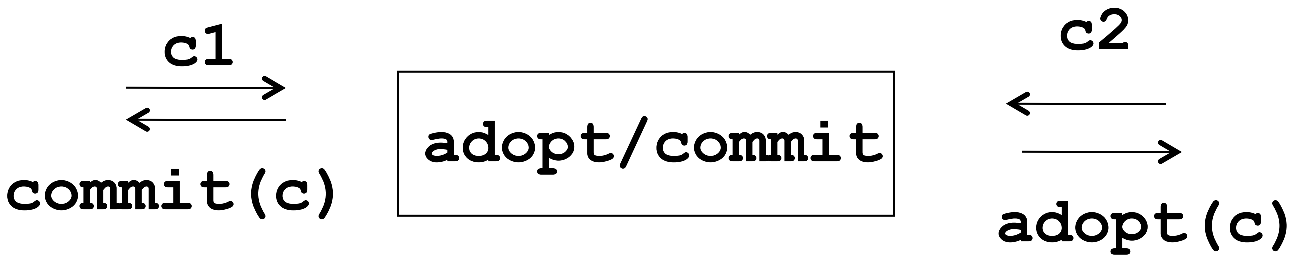
```
while(true)
  for j = 1 to k: com(j) = commands(j).next()
  kVectC = kVectCons.next()

  (c,i) = kVectC.propose(com)
  check other processes for any missing c'
  sM(i).perform(c)
  inform other processes about c
```

Generalized Universality



1st key idea (ensuring safety)



c1

commit(c)

adopt/commit

c2

adopt(c)

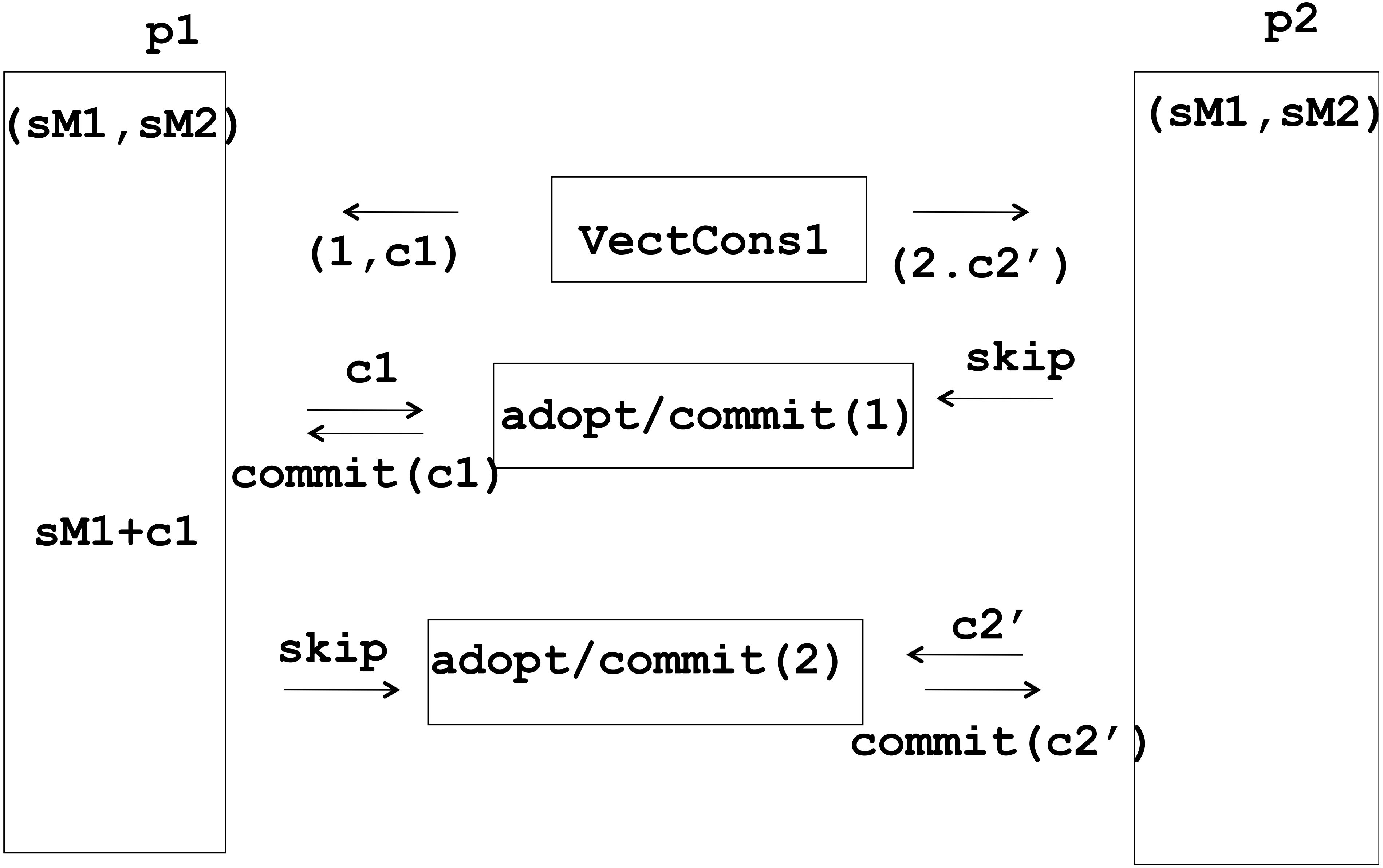
```
write (c)
if there is only c, write (commit, c)
if there is only (commit, c), return(commit, c)
if there is (commit, c’), return(adopt, c’)
else return (adopt, c)
```

Adopt/commit

- ***Invariant (1)***: if a value v is committed then no other value is returned

- ***Invariant (2)***: if all processes propose the same command then the command is committed

Generalized Universality



p1

p2

(sM1,sM2)

(sM1,sM2)

VectCons1

(1,c1)

(2.c2’)

c1

skip

adopt/commit(1)

commit(c1)

sM1+c1

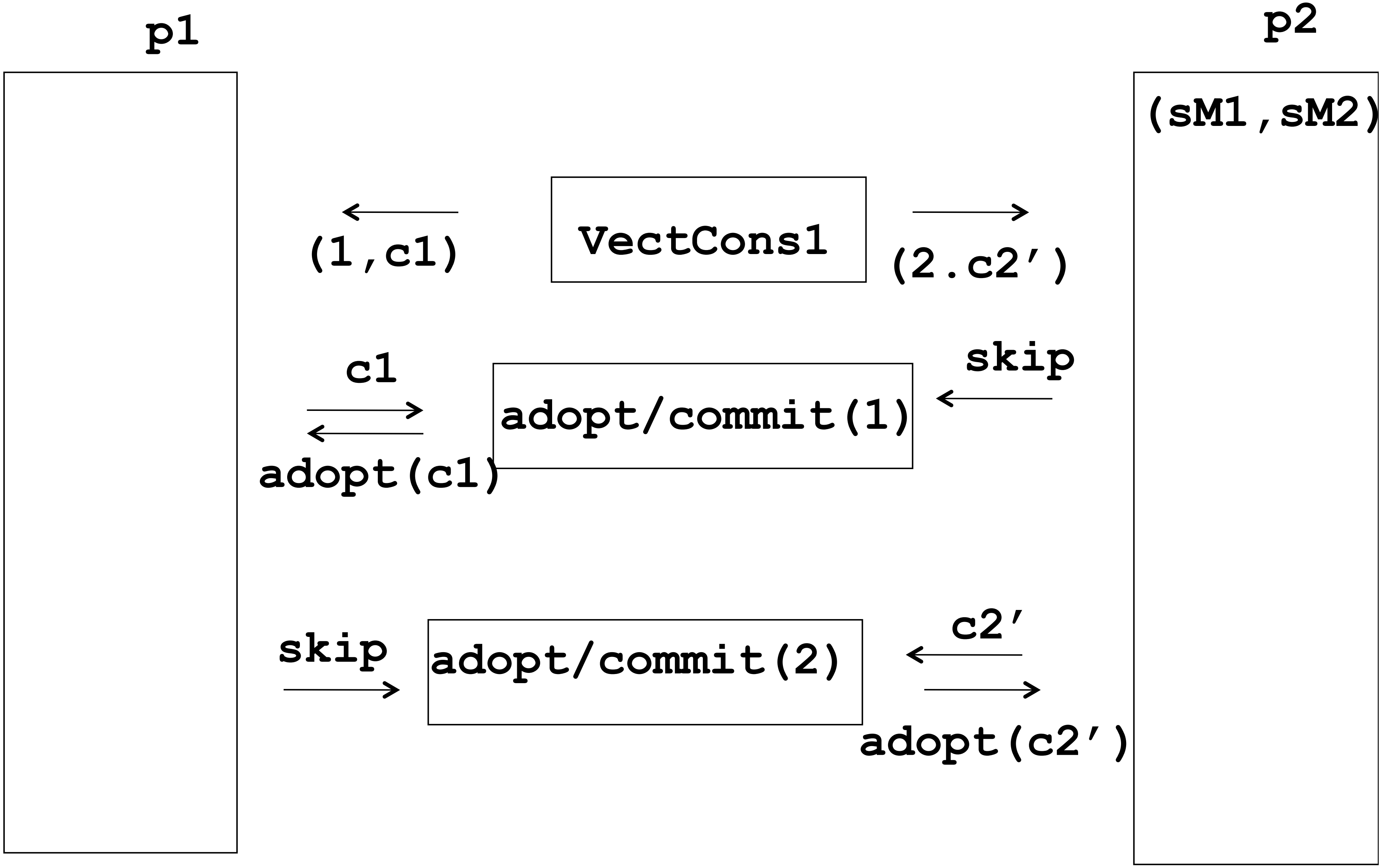
skip

adopt/commit(2)

c2’

commit(c2’)

Problem with liveness



p1

p2

(sM1,sM2)

(1,c1)

VectCons1

(2.c2′)

c1

adopt/commit(1)

skip

adopt(c1)

skip

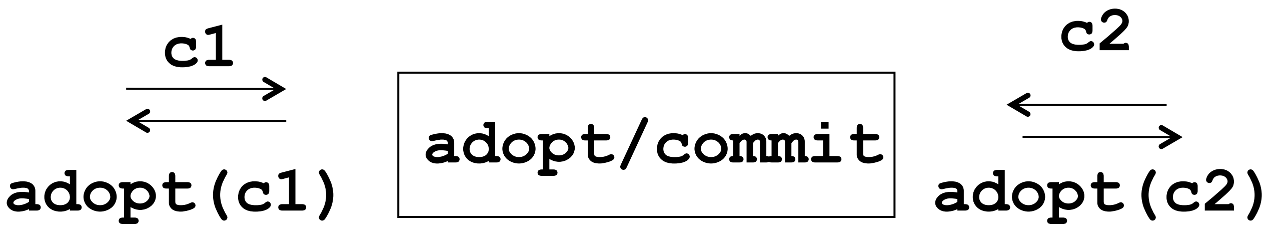
adopt/commit(2)

c2′

adopt(c2′)

2nd key idea (ensuring liveness)

Exploit success first



c1

adopt(c1)

adopt/commit

c2

adopt(c2)

Can it be that no command is committed? i.e., if every adopt/commit box has one process proposes skip

Generalized universality (step 0)

- newCom = commands.next()
- while(true)
-   kVectC = kVectCons.next()

Generalized universality (step 1)

- …
- (c,i) = kVectC.propose(newCom)
- …

Generalized universality (step1-2)

- …
- (c,i) = kVectC.propose(newCom)
- vect(i) = commitment(i,c)
- …

Generalized universality (step1-2-2’)

- …
- (c,i) = kVectC.propose(newCom)
- vect(i) = commitment(i,c)
- for j = 1 to k except i:
    - vect(j) = commitment(newCom(j))

    …

Generalized universality (step 3)

```
…
for i = 1 to k
▪ if  ok(vect(i)) then
    ▪ sM(i).perform(vect(i))
    ▪ newCom(i) = commands(i).next()
▪ else
    ▪ newCom(i) = vect(i)
```

Generalized universality (step 3’)

```
…
for i = 1 to k
▪ If older(newCom(i),vect(i)) then
                              sM(i).perform(newCom(i))
▪ If no(vect(i)) then newCom(i) = vect(i)
▪ else
▪ sM(i).perform(vect(i))
▪ If  vect(i) = newCom(i) then
    ▪ newCom(i) = commands(i).next()
▪ add(newCom(i),vect(i))
```

Commitment

- ***Safety***: a process does not perform a command unless all others know the command

- ***Liveness***: at least one process executes a command in every round

NB. Every correct process executes at least one command every two rounds

Act1: Universality

Turing

Act 2: Modern Universality

Turing + Lamport

Act 3: Generalized Universality