149th NII Shonan Meeting

Distributed Algorithms for Robot Systems

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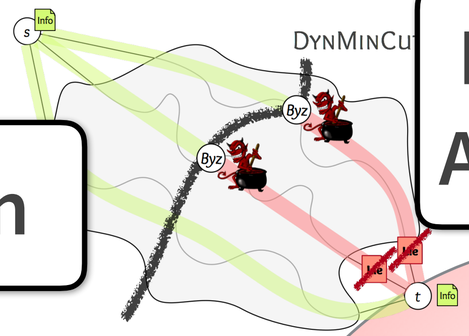
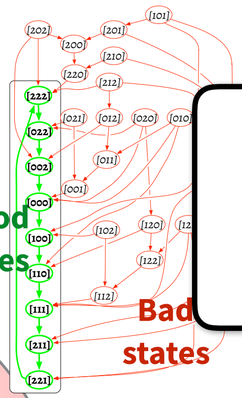
Research Area(s)

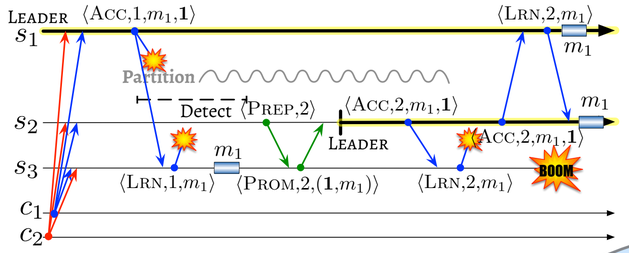


Blockchain

Byzantine Agreement



Gathering, Pattern Formation

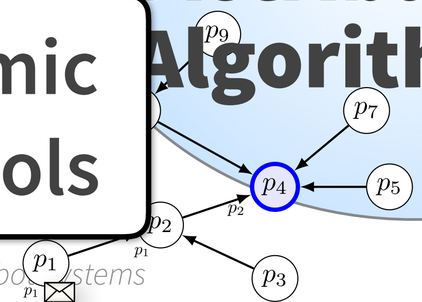


Dependable Systems

Self-Stabilization

```
class Arbitr
{
  private de
  private va
  private va
  private va
  private va
  private var announced = false

  private def visitNextChild() {
    children match {
      case next :: tail    => SEND (Token(me, next,   maxID)) ; children = tail  // Rule 1
      case Nil if ! isRoot => SEND (Token(me, parent, maxID))                    // Rule 2
      case Nil if isRoot   => SEND (AnnounceLeader(me, neighbors+me, me))        // End
  } }

  def onSend = {
    case Candidate if color == Red   => visitNextChild()
    case Candidate if color == Black => /* IGNORE */
  }

  listenTo(classOf[Token])
  listenTo(classOf[AnnounceLeader])
  def onReceive = {
    case Token(_,_,pid,_) if pid < ma
    case Token(_,_,pid,_) if pid == m
    case Token(from,_,pid,_)
      color = Black ; maxID = pid ; pa
      children = (neighbors - from).t
      visitNextChild()

    case AnnounceLeader(_,_,_,_) if a
    case AnnounceLeader(from,_,leader
      announced = true
      SEND (AnnounceLeader(me, neighb
      DELIVER (Elected(Some(leader)))
} }
```

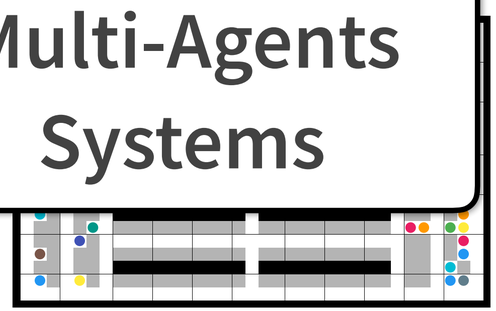
Distributed Algorithms



Epidemic Protocols

Multi-Robots Systems

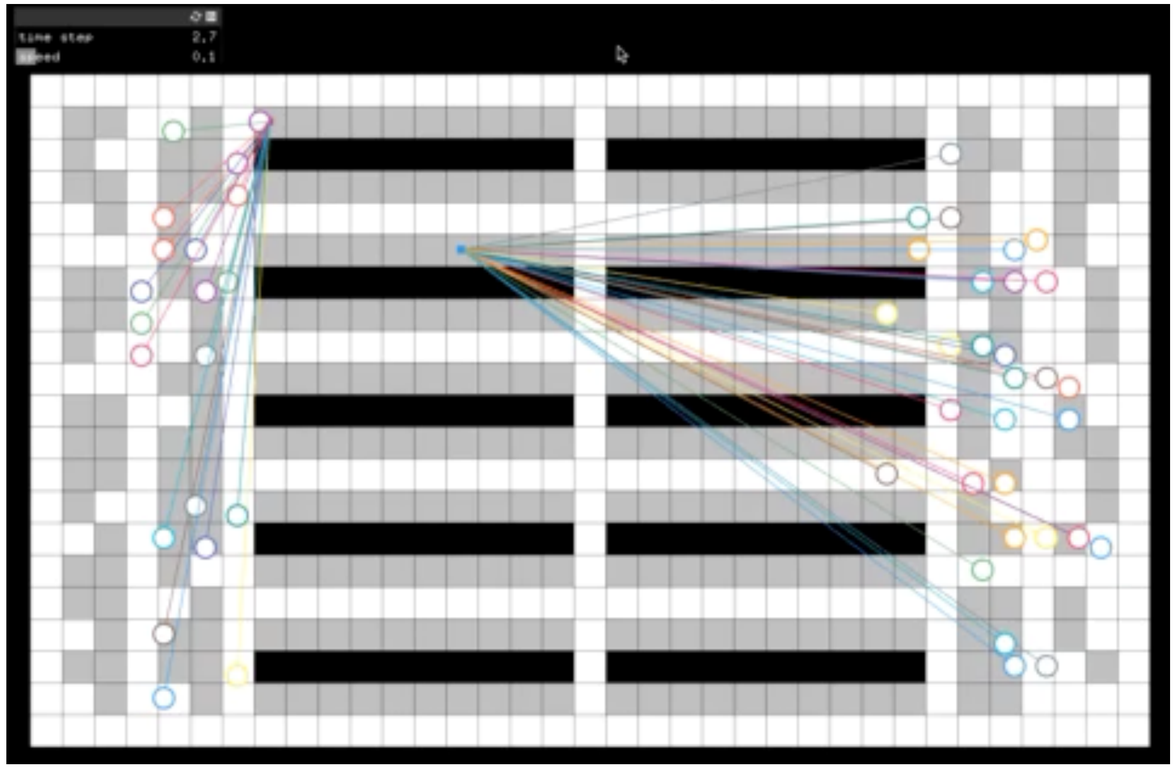
Cooperati Robotics



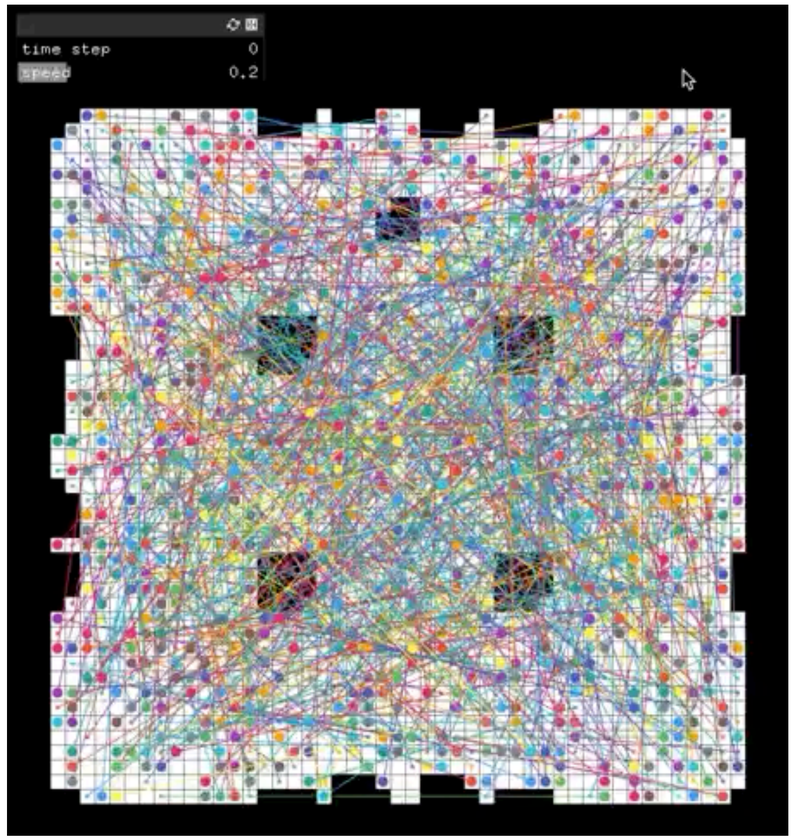
Multi-Agents Systems

Multi-Agent Systems

Pickup and Delivery



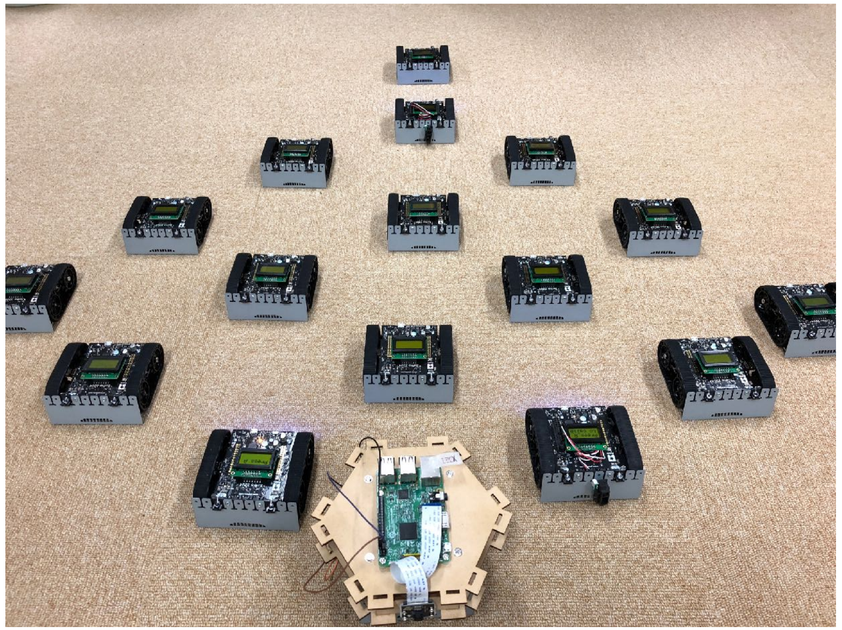
Path Finding

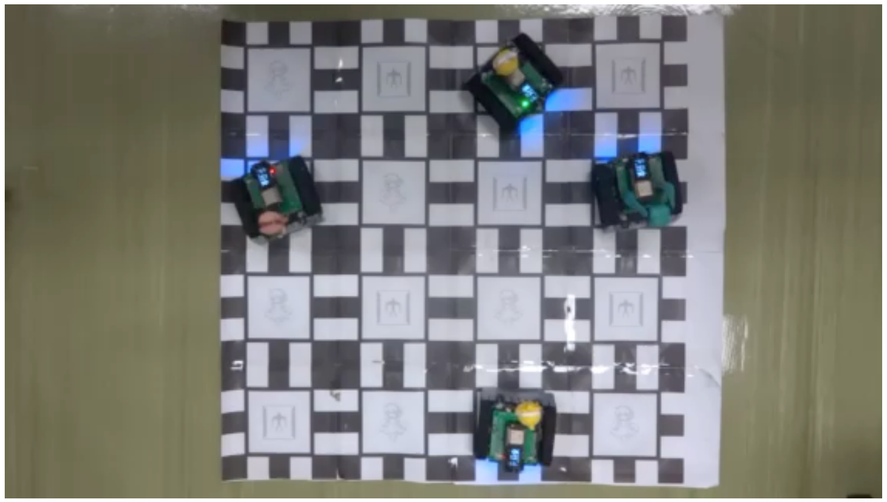


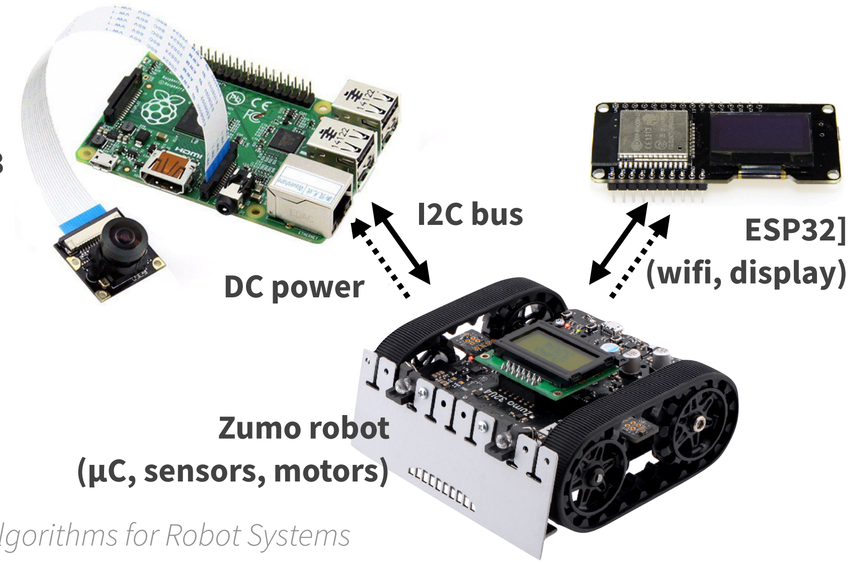
K.Okumura, M.Machida, X.Défago, Y.Tamura: **Priority Inheritance with Backtracking for Iterative Multi-agent Path Finding**. IJCAI 2019, to appear

Prototyping Platform

- **Robot Platform**
  - 17 robots
  - Zumo + ESP32 / Raspberry Pi 3
  - used for prototyping
  - fully decentralized control
  - local communication





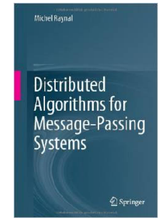


Non-Research

Neko > ScalaNeko > Ocelot

- **What?**
  - DSL for Distributed Algorithms
- **Purpose**
  - **Teaching** / Prototyping
- **Timeline**
  - 2000's Neko framework (EPFL/JAIST) w/Peter Urban
  - 2008 Scala wrappers for Neko (JAIST)
  - 2012 ScalaNeko (JAIST)
  - 2017 Ocelot (Tokyo Tech)

Models



Active *(spanning tree)*

when $r = 1, 2, \ldots, D$ **do**
begin synchronous round
(1) **for each** $j \in neighbors_i$ **do** send UPDATE$(length_i)$ to p_j **end for**
(2) **for each** $j \in neighbors_i$ **do** receive UPDATE$(length_j)$ from p_j **end for**
(3) **for each** $k \in \{1 \ldots n\} \setminus \{i\}$ **do**
(4) **let** $length\_ik = \min_{j \in neighbors_i}(lg_i[j] + length_j[k])$
(5) **if** $(length\_ik < length_i[k])$ **then**
(6) $length_i[k] \leftarrow length\_ik$
(7) $routing\_to_i[k] \leftarrow$ a neighbor that realizes the previous minimum
(8) **end if**
(9) **end for.**
end synchronous round

Blocking *(random leader elect.)*

1 $rd_i \leftarrow$ random$(1, n)$;
2 broadcast RANDOM(rd_i);
3 **wait for** a message RANDOM(rd_x) **from each** process p_x;
4 $elected_i \leftarrow (\sum_{x=1}^{n} rd_x) \bmod (n + 1)$.

Reactive *(mutex: drinking philosophers)* Models

```
1  operation acquire_mutex() is
2      cs_state_i ← trying;
3      for each j ∈ R_i do send REQUEST() to p_j;
4      wait (R_i = ∅);
5      cs_state_i ← in;
6      for each j ∈ {1, ..., n} \ {i} do perm_state_i[j] ← used; end for.
7
8  operation release_mutex() is
9      cs_state_i ← out;
10     for each j ∈ perm_delayed_i do send PERMISSION({i, j}) end for;
11     R_i ← perm_delayed_i;
12     perm_delayed_i ← ∅.
13
14 when REQUEST() is received from p_j do
15     prio_i ← (cs_state_i = in)
16                 ∨((cs_state_i = trying) ∧ (perm_state_i[j] = new))
17                 ∨((cs_state_i = trying) ∧ (j ∈ R_i));
18     if (prio_i) then
19         perm_delayed_i ← perm_delayed_i ∪ {j}
20     else
21         send PERMISSION({i, j}) to p_j
22         R_i ← R_i ∪ {j};
23         if (cs_state_i = trying) then send REQUEST() to p_j end if
24     end if.
25
26 when PERMISSION({i, j}) is received from p_j do
27     R_i ← R_i \ {j}
28     perm_state_i[j] ← new.
```

Active *(spanning tree)*

```
when r = 1, 2, ..., D do
begin synchronous round
(1)  for each j ∈ neighbors_i do send UPDATE(length_i) to p_j end for
(2)  for each j ∈ neighbors_i do receive UPDATE(length_j) from p_j end for
(3)  for each k ∈ {1...n} \ {i} do
(4)    let length_ik = min_{j∈neighbors_i}(lg_i[j] + length_j[k])
(5)    if (length_ik < length_i[k]) then
(6)      length_i[k] ← length_ik
(7)      routing_to_i[k] ← a neighbor that realizes the previous minimum
(8)    end if
(9)  end for.
end synchronous round
```

Blocking *(random leader elect.)*

```
1  rd_i ← random(1, n);
2  broadcast RANDOM(rd_i);
3  wait for a message RANDOM(rd_x) from each process p_x;
4  elected_i ← (∑_{x=1}^{n} rd_x) mod (n + 1).
```

$$\textbf{wait } (R_i = \emptyset);$$

HelloWorld

```
class GreeterA(p: ProcessConfig) extends ActiveProtocol(p)
{
  listenTo(classOf[Greetings])
  def run() {
    SEND(Greetings(me, neighbors, "Hello Shonan!"))
    for (_ <- neighbors) {
      Receive {
        case Greetings(from, _, msg) => println(s"$me got from $from: $msg")
      }
    }
  }
}

case class Greetings(from: PID, to: Set[PID], msg: String)
  extends MulticastMessage

object HelloWorldMain
  extends Main(topology.Grid(2,2))(ProcessInitializer { new GreeterA(_) })
```

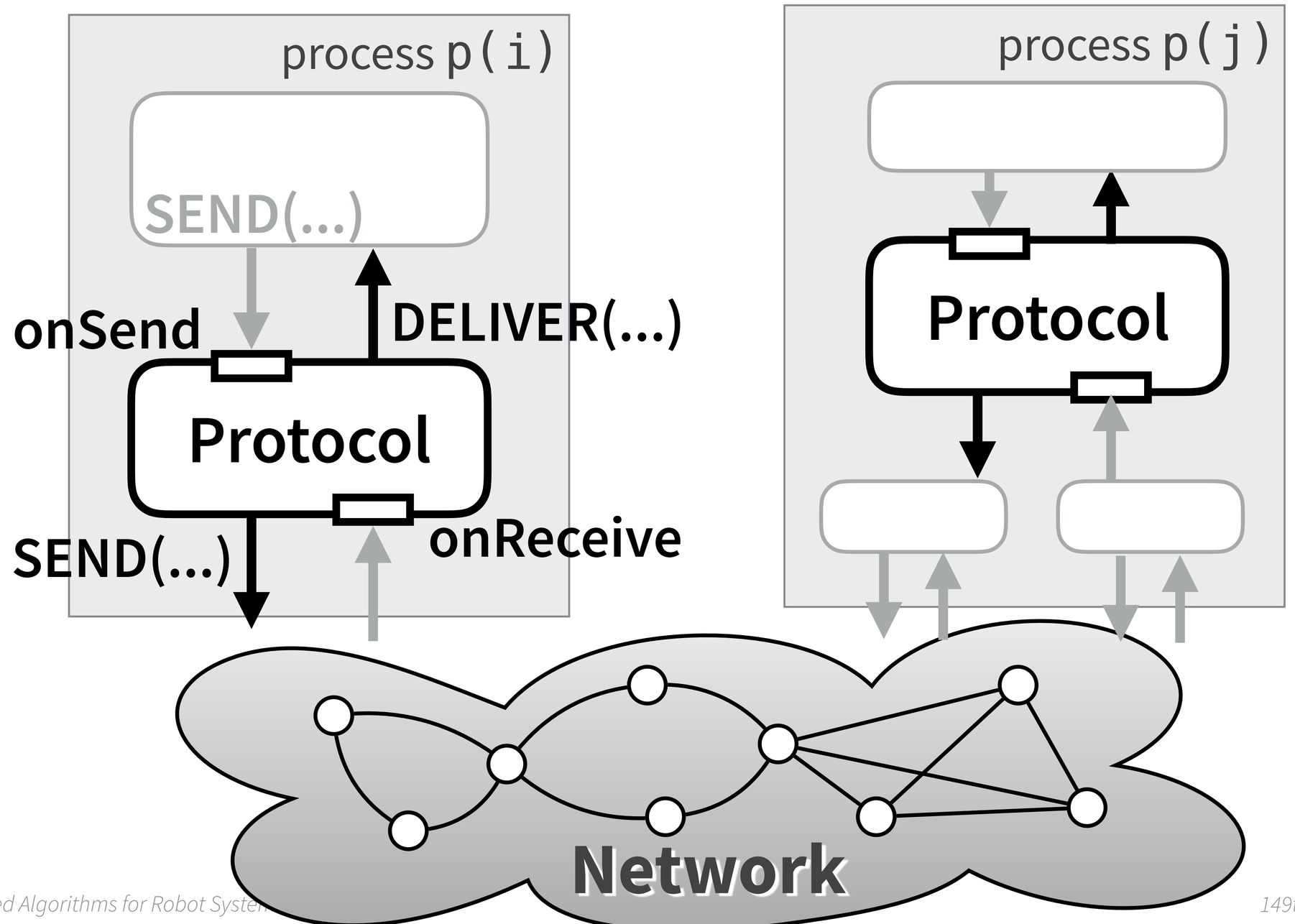
HelloWorld (react)

```
class GreeterR(p: ProcessConfig) extends ReactiveProtocol(p)
{
  override def preStart() = {
    SEND(Greetings(me, neighbors, "Hello Shonan!"))
  }

  listenTo(classOf[Greetings])
  def onReceive = {
    case Greetings(from, _, msg) => println(s"$me got from $from: $msg")
  }
  def onSend = PartialFunction.empty
}

case class Greetings(from: PID, to: Set[PID], msg: String)
  extends MulticastMessage

object HelloWorldMain
  extends Main(topology.Grid(2,2))(ProcessInitializer { new GreeterR(_)})
```

Hello World (hybrid)

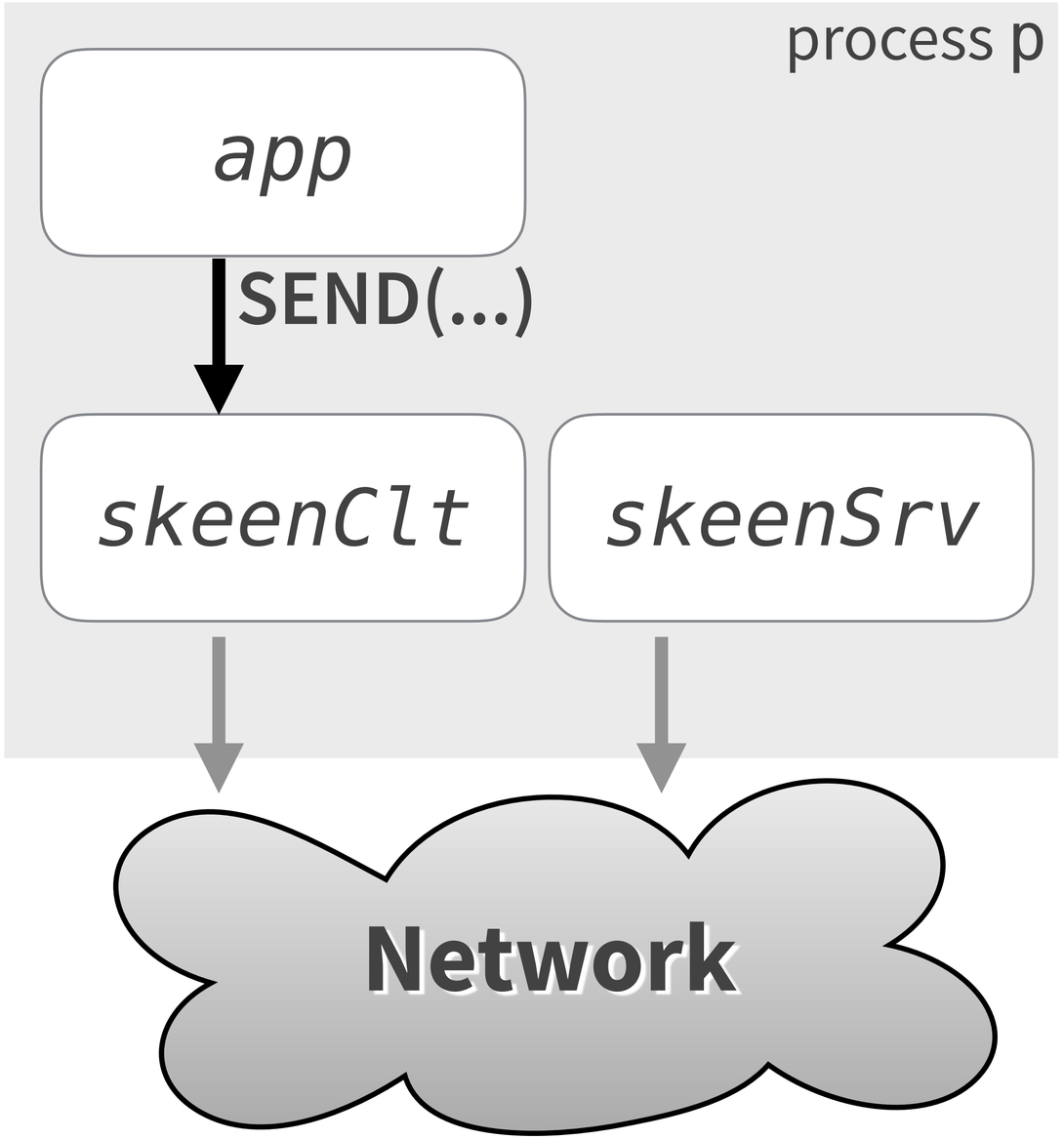
```
class GreeterH(p: ProcessConfig) extends ActiveProtocol(p)
{
  def run() {
    SEND(Greetings(me, neighbors, "Hello World!"))
  }

  listenTo(classOf[Greetings])
  override def onReceive = {
    case Greetings(from, _, msg) => println(s"$me got from $from: $msg")
  }
}

case class Greetings(from: PID, to: Set[PID], msg: String)
  extends MulticastMessage

object HelloWorldMain
  extends Main(topology.Grid(2,2))(ProcessInitializer { new GreeterH(_) })
```

Overview

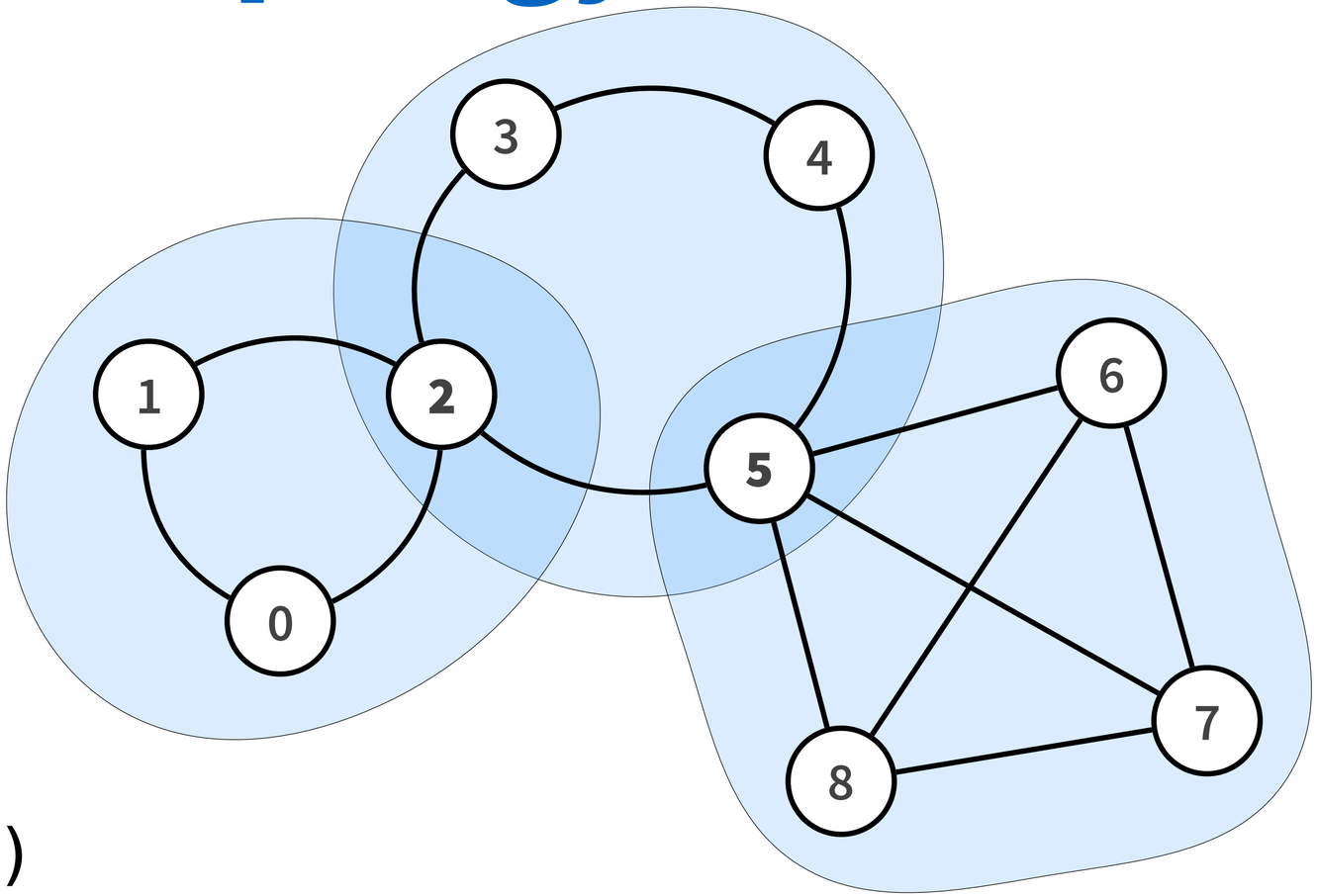

process p(i)
SEND(...)
onSend
DELIVER(...)
Protocol
SEND(...)
onReceive
process p(j)
Protocol
Network

Initializer & Composition

```
object SkeenTestApp
  extends Main(topology.Clique(10))(
  ProcessInitializer { p =>
    val app       = new BroadcasterApp(p)
    val skeenClt  = new Skeen.Client(p)
    val skeenSrv  = new Skeen.Server(p)

    app --> skeenClt
  })
```



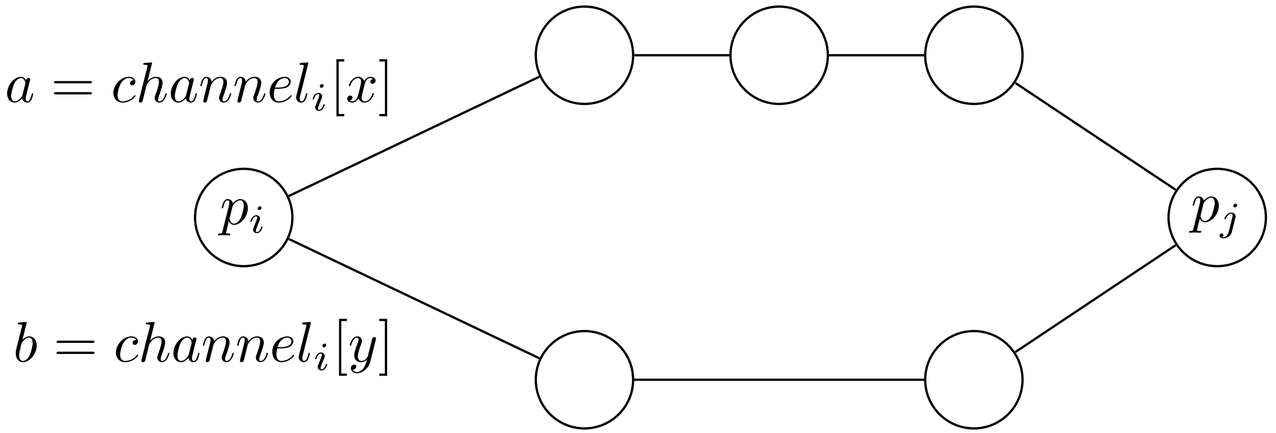
System Topology




```
object CutVerticesMain
  extends Main(
    topology.Clique(0 to 2)
      union topology.Ring(2 to 5)
      union topology.Clique(5 to 8)
  )(ProcessInitializer { new CutVertices(_) })
```

Cut Vertices

```
private var r_i = 0
private var inf_i = Set(me)
private var new_i = Set(me)
private var com_with_i = neighbors
private var routing_to_i = Map(me -> me)
private var dist_i       = Map(me -> 0)
private var relationR =
  neighbors.zipWithIndex.map(pi => pi._1 -> pi._2).toMap

def run() {
  while( new_i.nonEmpty ) {
    /* begin asynchronous round */
    r_i += 1
    SEND(Msg(me, com_with_i, r_i, new_i))
    new_i = Set.empty

    for (x <- com_with_i) {
      ReceiveOnly {
        case Msg(`x`,_,r,new_m) if r == r_i =>
          if (new_m.isEmpty) { com_with_i -= x }
          else {
            val aux = new_m diff (inf_i union new_i)
            for (id <- new_m) {
              if (! (inf_i union new_i).contains(id)) {
                routing_to_i = routing_to_i.updated(id, x)
                dist_i       = dist_i.updated(id, r_i)
              }
              else if (dist_i.get(id).exists(d => r_i == d || r_i == d+1)) {
                val y = routing_to_i(id)
                /* x,y in same biconnected component */
                relationR = transitiveAppend(relationR, (x,y))
            } }
            new_i = new_i union aux
    } }   }
    inf_i = inf_i union new_i
    /* end asynchronous round */
  }
  SEND ( Msg(me, com_with_i, r_i+1, new_i) )
}
```



Reactive *(mutex: drinking philo)* Models

```
1  operation acquire_mutex() is
2      cs_state_i ← trying;
3      for each j ∈ R_i do send REQUEST() to p_j;
4      wait (R_i = ∅);
5      cs_state_i ← in;
6      for each j ∈ {1, ..., n} \ {i} do perm_state_i[j] ← used; end for.
7
8  operation release_mutex() is
9      cs_state_i ← out;
10     for each j ∈ perm_delayed_i do send PERMISSION({i, j}) end for;
11     R_i ← perm_delayed_i;
12     perm_delayed_i ← ∅.
13
14 when REQUEST() is received from p_j do
15     prio_i ← (cs_state_i = in)
16                 ∨((cs_state_i = trying) ∧ (perm_state_i[j] = new))
17                 ∨((cs_state_i = trying) ∧ (j ∈ R_i));
18     if (prio_i) then
19         perm_delayed_i ← perm_delayed_i ∪ {j}
20     else
21         send PERMISSION({i, j}) to p_j
22         R_i ← R_i ∪ {j};
23         if (cs_state_i = trying) then send REQUEST() to p_j end if
24     end if.
25
26 when PERMISSION({i, j}) is received from p_j do
27     R_i ← R_i \ {j}
28     perm_state_i[j] ← new.
```

$$\textbf{wait } (R_i = \emptyset);$$

Drinking Philosophers

```
class ChandyMisra(p: ProcessConfig)
  extends ReactiveProtocol(p)
{
  private var cs_state_i: ChannelState = OUT
  private var perm_delayed_i = Set.empty[PID]
  private var perm_state_i = ALL.map(_ -> USED).toMap
  private var R_i = ALL.filter(me < _)

  def onSend = {
    case MutexClient.Request =>
      cs_state_i = TRYING
      SEND( Request(me, R_i) )
      if (R_i.isEmpty) enterCS()

    case MutexClient.Release =>
      cs_state_i = OUT
      perm_delayed_i.foreach(j => SEND(Permission(me, j)))
      R_i = perm_delayed_i
      perm_delayed_i = Set.empty
  }

  private def enterCS() {
    assert(R_i.isEmpty)
    cs_state_i = IN
    perm_state_i = perm_state_i.mapValues(_ => USED)
    DELIVER(MutexClient.CanEnter)
  }
```

```
  listenTo(classOf[Request])
  listenTo(classOf[Permission])
  def onReceive = {
    case Request(p_j, _) =>
      val prio_i =
        (cs_state_i == IN) ||
          ((cs_state_i == TRYING) &&
              ((perm_state_i(p_j) == NEW) ||
               (R_i contains p_j)))
      if (prio_i) { perm_delayed_i += p_j }
      else {
        SEND( Permission(me, p_j) )
        R_i += p_j
        if (cs_state_i == TRYING)
          SEND( Request(me, Set(p_j)))
      }

    case Permission(j, i) =>
      R_i -= j
      perm_state_i = perm_state_i.updated(j, NEW)
      if (R_i.isEmpty) enterCS()

    case _ => /* ignore */
  }
}
```

Thank You

- **Requirements**
  - Support many models
  - Support diff. levels of abstraction
  - Reduced boilerplate
  - Readable
  - Flexibility / composable
  - Robustness
  - Must run on laptop