Distributes Systems

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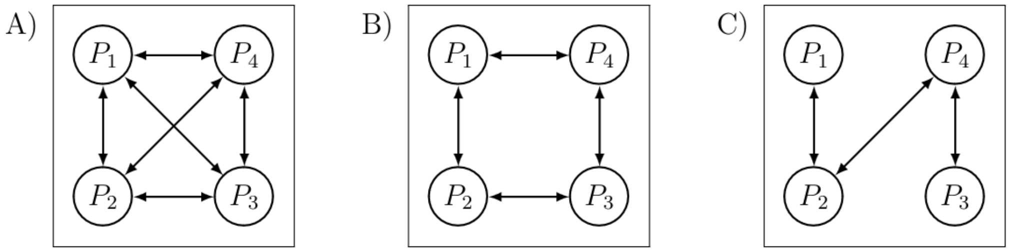
1. System Models

Consider the three peer-to-peer systems shown below. Each of these comprises four processes P_1, P_2, P_3 and P_4 connected through bidirectional communication channels which are depicted by the edges in the graph. Furthermore, each system is *synchronous* (as defined in the lecture), with an upper bound d on message delay.



Assume you are asked to design communication protocols for each of these systems, such that the following specification is implemented:

`A message` m `sent by any process` P_i `is delivered to all other processes` $P_j, j \neq i$`, exactly once and all at the same time.`

A colleague of yours proposes the following protocol for System A (fully interconnected):

A) sender protocol:

```
t <- clock.now();
send (m, t) to neighbours;
```

A) receiver protocol:

```
(m, t) <- receive();
delayUnit(t + d);
deliver(m);
```

a) With the described system model, is it possible to modify the proposed protocol such that it meets the specification? Justify!

The assumption must be made that all the processes P_j for $i \neq j$ receive the messages before the upper bound is hit. With the communication being synchronous that might not be the case, since all sends and all receives are blocking. Since the loop on the sender side each iteration is waiting until the send call is executed and until the receive call was executed and the receiver send it's acknowledge to the sender. Under circumstances this overhead causes a huge enough delay that the upper delay already expired and since the sender is not checking if its sending messages while the delay is not expired it can not be sure that the messages are all delivered to the receiving processes at the same point of time. Further the receivers are acknowledging the received messages before evaluating if the contract to respect the delay can be met and errors only occur after the blocking of the receive call when the communication with P_i has already happened. In conclusion I would suggest implementing a mechanism to check on the sender side if the delay requirement can still be met:

A) sender protocol:

```
t <- clock.now() + d;
i <- 0;
for neighbours.length() < i {
```

```
  send (m, t) to neighbours[i];
  if t < clock.now() {
    error(wasn't able to deliver message in time);
  }
  i <- i + 1;
}
```

A) receiver protocol:

```
(m, t) <- receive();
delayUnit(t);
deliver(m);
```

If no error was thrown the sender can now be sure that all receivers were able to get their message at the same point in time.

b) What additional assumptions must be added to the system model (interaction and failure model) such that the proposed protocol meets the specification?

As stated in a) the proposed protocol doesn't account for the fact that receivers might receive messages at the point of time that is already bigger than the point of time describing the delay. So in order for the proposed protocol to work the assumption must be made that for all receivers the delay is not hit before the receive call exits it's blocking state.

For the remainder of this question, the additional assumptions that you derived in part b) are added to the system model!

c) With your new system model, design a similar procol fullfilling the given specification for System B with minimal communication and storage requirements!

B) sender protocol:

```
t <- clock.now() + d;
for v in neighbours {
  // this.index is the index of this process
  send (m, t, this.index) to neighbours[i];
  if t < clock.now() {
    error(wasn't able to deliver message in time);
  }
}
```

B) receiver protocol:

```
// index is the index sent by the sender
(m, t, index) <- receive();
for v in neighbours {
  if index < 0 {
    continue
  }
  if index == v.index {
    continue
  }
  if v.index != this.index + 1 and v.index != this.index - 3{
    continue
  }
  send (m, t, -1) to v;
}
delayUnit(t);
deliver(m);
```

This implementation works under the assumption that we only forward the message to one more process after the initial round of sending. The original sender sends his index with the send so that the receiving processes don't forward the message to the sender. Also the processes only forward the message to processes with an index of their index incremented by one or their index minus three (catching the case that P_1 is the process needing the message to be forwarded). This ensures that the receiving processes don't forward the message both.

Also the process receiving the forwarded message knows that it should not further forward because the index -1 is sent when a message gets forwarded. That way it is ensured that a message gets only forwarded one "round".

d) With your new system model, design a similar protocol fullfilling the given specification for System C with minimal communication and storage requirements!

C) sender protocol:

```
t <- clock.now() + d;
for v in neighbours {
  // this.index is the index of this process
  send (m, t, this.index) to neighbours[i];
  if t < clock.now() {
    error(wasn't able to deliver message in time);
  }
}
```

C) receiver protocol:

```
// index is the index sent by the sender
(m, t, index) <- receive();
for v in neighbours {
  if index == v.index {
    continue
  }
  send (m, t, this.index) to v;
}
delayUnit(t);
deliver(m);
```

This time we don't have to cover the case that multiple processes might be trying to forward a message to the same process. Thats why it is enough to limit a receiver to not be allowed to forward the message it received to the process it received it from.

2. Three-Army-Problem

In the following we discuss a variation of the Two-Army-Problem presented in the lecture. Similar to the Two-Army-Problem, the goal of the Three-Army-Problem is to reach agreement among three divisions about the order time of the attack. In this case, it must be guranteed that the largest division attack last.

The protocol must be clearly devided into two phases:

1. The divisions coordinate the **order of attack** (by division size)

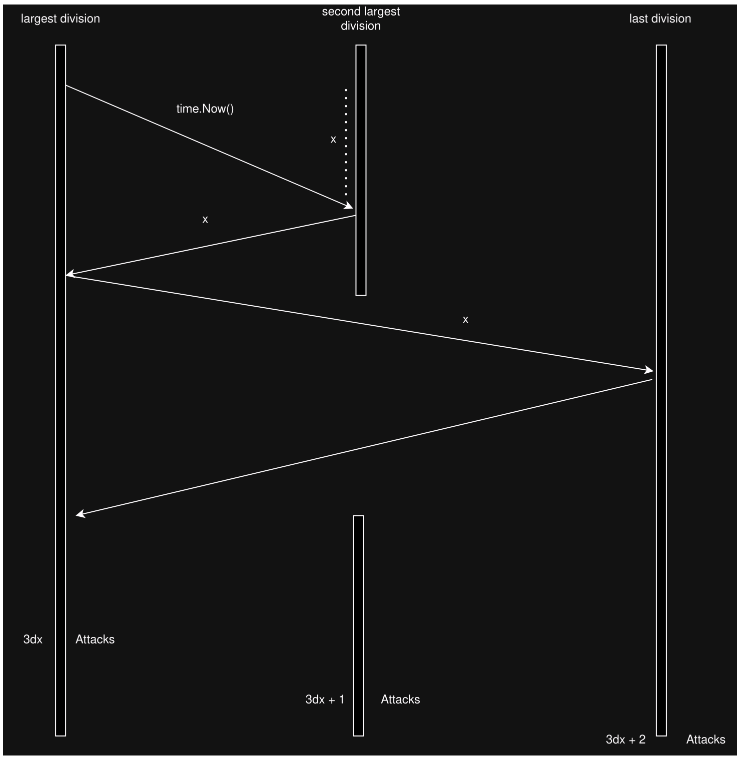
2. The largest division determines the **time of attack** and informs the other divisions.

Furthermore, attacks of subsequent divisions should take place **at least 1 minute apart**.
Assume a synchronous system, where no errors occur on the communication channel. A messenger between any two divisions may take up to d minutes. You may assume that all divisions are of different size. An arbitrary division initiates the protocol at time t_0.
Note: There is no drift between the division's clocks.

a) Here, assume that the clocks of all three divisions are perfectly synchronized (i. e. no drift, no clock skew). Briefly describe a protocol for the Three-Army-Problem that fulfils the following two conditions:

1. The time between the first attack and the last attack must be minimal.
2. The first attack should start as soon as possible (without violating the first condition).

Illustrate your protocol through a time-space-diagram.
Provide the worst-case attack times (i. e. messenger time = d) for each division.



The first division sends the messenger to the second division and sends it's time stamp as the message. Then the second division sends the messenger back for the acknowledge with the time stamp when they received the message. Then the messenger is send to the third devision with the message of the how long it took the messenger to deliver the first message. With that information exchange we let the first division attack after the duration of it's first send which will be $\leq d$ we will call that vairable x and $3d$ since the other two divisions can't know how long their acknowledges took and also the second division can't know how long it took to deliver the message to the third division. We let the second division attack one second after the first division and the third two seconds after. In other words we let attack the first division at $3dx$ the second at $3dx + 1$ and the third $3dx + 2$ with x being $\leq d$. In the worst case x will be equal d and therefore in the worst case the first division attacks at $4d$, the second at $4d + 1$ and the third at $4d + 2$. The only advantage we could take here was that we can measure how long the first send actually took and let all divisions know how long it took and eventually we don't have to wait one full delay.

b) Now, assume that there may be an arbitrary clock skew (but no drift) between the clocks of different divisions! Design a protocol that fulfils the two conditions given in part a), but with reversed priority, that is:

1. The first attack must start as soon as possible.

2. The time between the first attack and the last attack should be minimal (without violating the first condition).

Again, briefly describe your protocol and illustrate it through a time-space-diagram and provide the worst-case attack times (i. e. messenger time = d) for each division.

3. Unreliable and Reliable Communication