Babel: A framework for developing performant and dependable distributed protocols

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Motivation

- Distributed protocol designs are often **simple** (in pseudocode), however implementing them is **error-prone and time consuming**, with lots of low level aspects, such as:
  - Networking
  - Concurrency
  - Multiplexing
  - Protocol interactions
  - …

Motivation

- We require a framework that **simplifies the development of distributed systems**:
  - **Abstracting low level aspects**: network, concurrency, timers, etc.
  - Without restricting **generability**, allowing implementing any distributed protocol.
  - **Performant** and allowing the implementation of **production-ready** systems.

Babel: Overview

- Java framework providing an **event driven programming model.**
- **Simplifies implementation** of distributed algorithms by trivially translating their specification (pseudo-code).
- Provided abstractions are sufficiently **generic** to support a wide variety of algorithms.
- Capable of supporting **production-ready performant** implementations.

Babel: Overview

- Java framework providing an **e**
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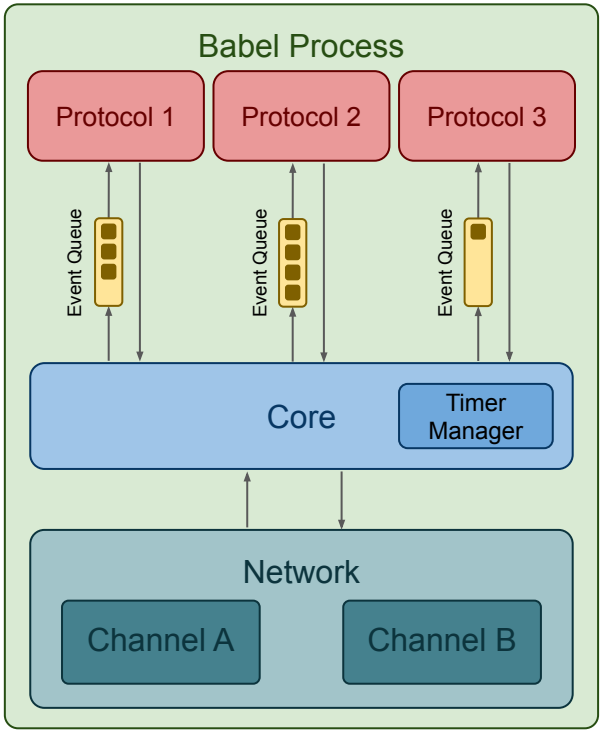
algorithms.

```
upon init do
    Send(JOIN, contactNode, myself);

upon Receive(JOIN, newNode) do
    trigger addNodeActiveView(newNode)
    foreach n ∈ activeView and n ≠ newNode do
        Send(FORWARDJOIN, n, newNode, ARWL, myself)

upon Receive(FORWARDJOIN, newNode, timeToLive, sender) do
    if timeToLive== 0||#activeView== 1 then
        trigger addNodeActiveView(newNode)
    else
        if timeToLive==PRWL then
            trigger addNodePassiveView(newNode)
        n ⟵ n ∈ activeView and n ≠ sender
        Send(FORWARDJOIN, n, newNode, timeToLive-1, myself)

upon dropRandomElementFromActiveView do
    n ⟵ n ∈ activeView
    Send(DISCONNECT, n, myself)
    activeView ⟵ activeView \{n}
    passiveView ⟵ passiveView ∪{n}

upon addNodeActiveView(node) do
    if node ≠ myself and node ∉ activeView then
        if isfull(activeView) then
            trigger dropRandomElementFromActiveView
        activeView ⟵ activeView ∪ node

upon addNodePassiveView(node) do
    if node ≠ myself and node ∉ activeView and node ∉ passiveView then
        if isfull(passiveView) then
            n ⟵ n ∈ passiveView
            passiveView ⟵ passiveView \{n}
        passiveView ⟵ passiveView ∪ node

upon Receive(DISCONNECT, peer) do
    if peer ∈ activeView then
        activeView ⟵ activeView \ {peer}
        addNodePassiveView(peer)
```

Babel: Architecture



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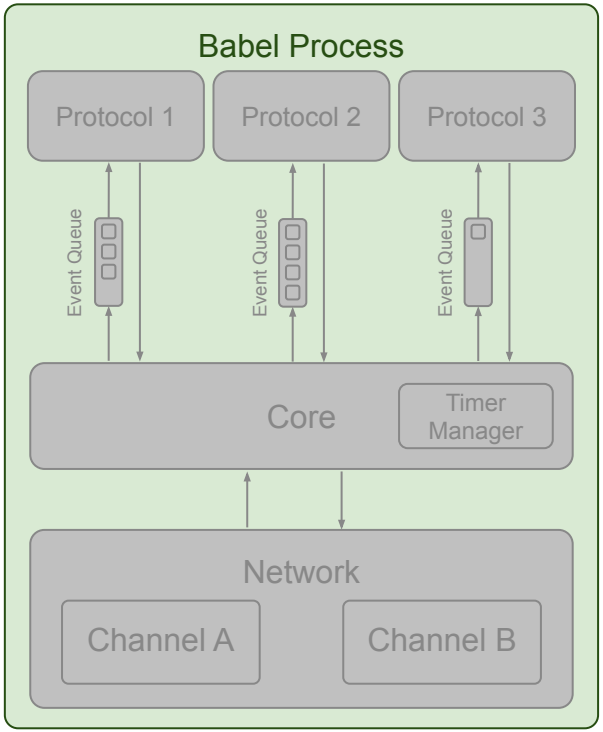

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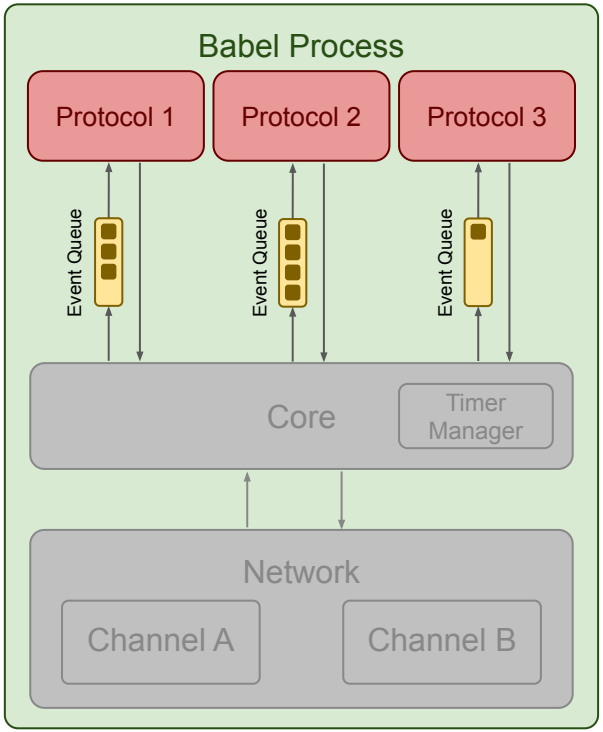

- Each *Babel process* represents a process of the distributed algorithm.
- *Protocols* are implemented by developers and encode the behavior of the algorithm.

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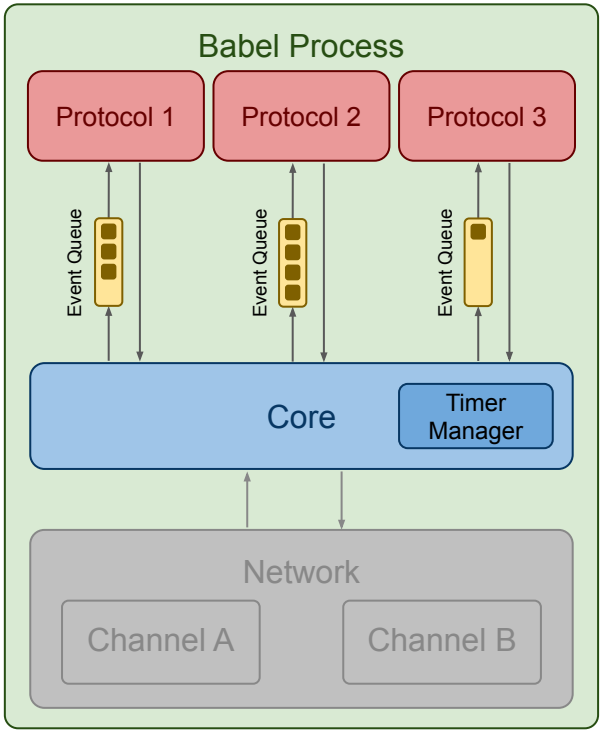

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- The *Core* coordinates and mediates interactions between protocols and processes.

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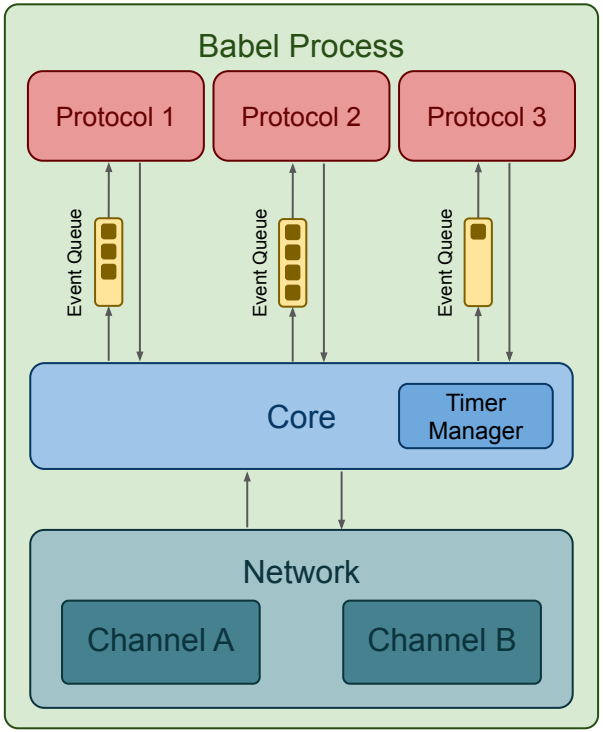

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- *Network channels* abstract communications between processes and provide different behaviours and guarantees.

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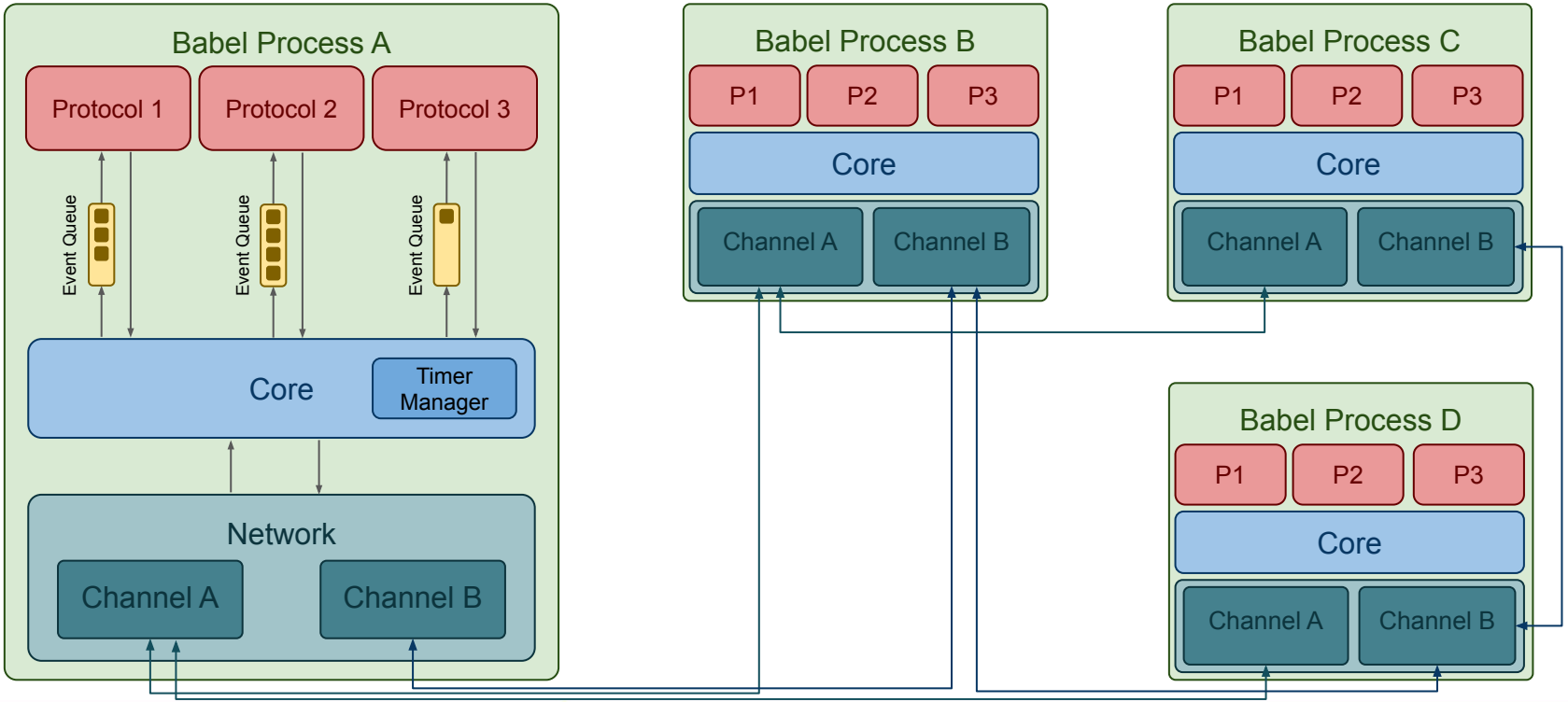

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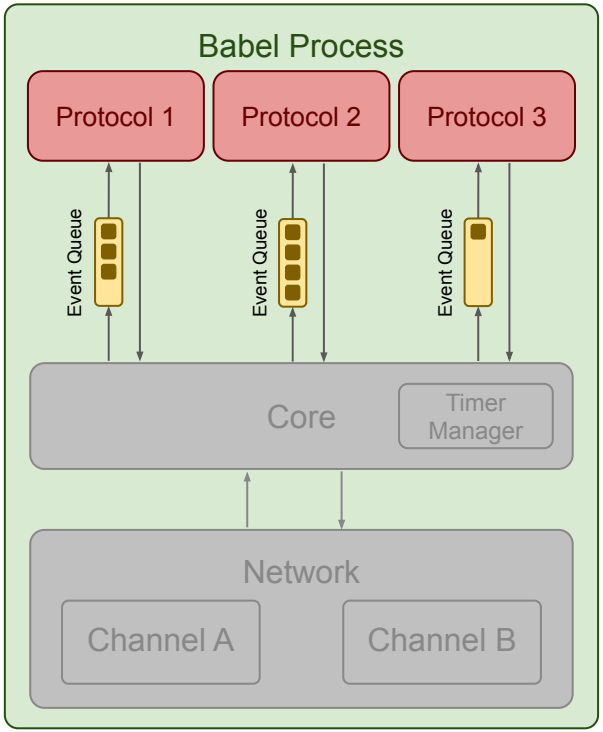

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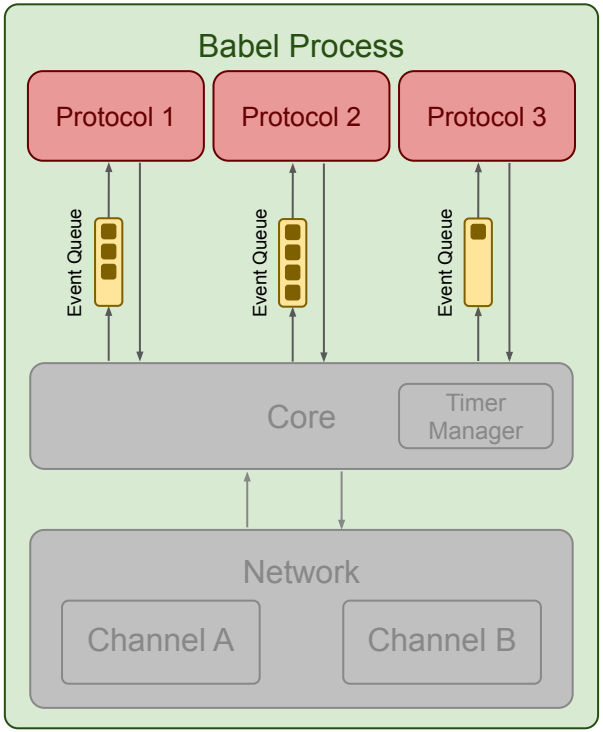

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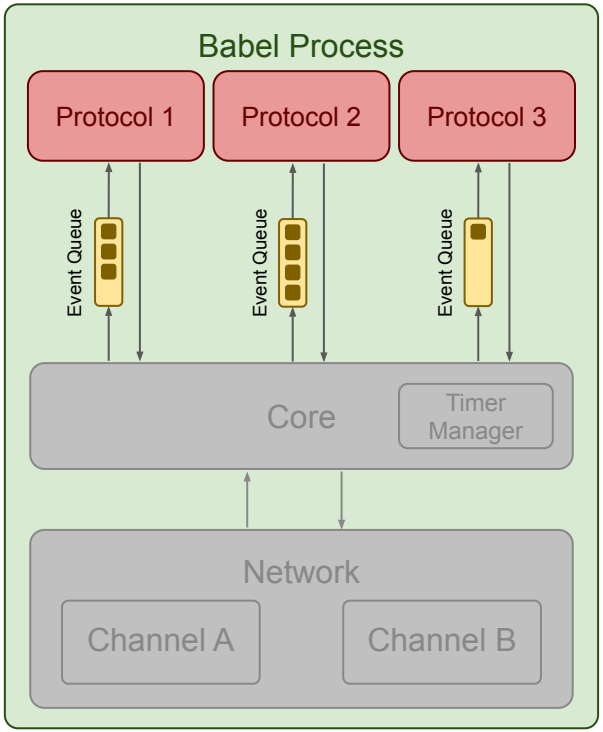

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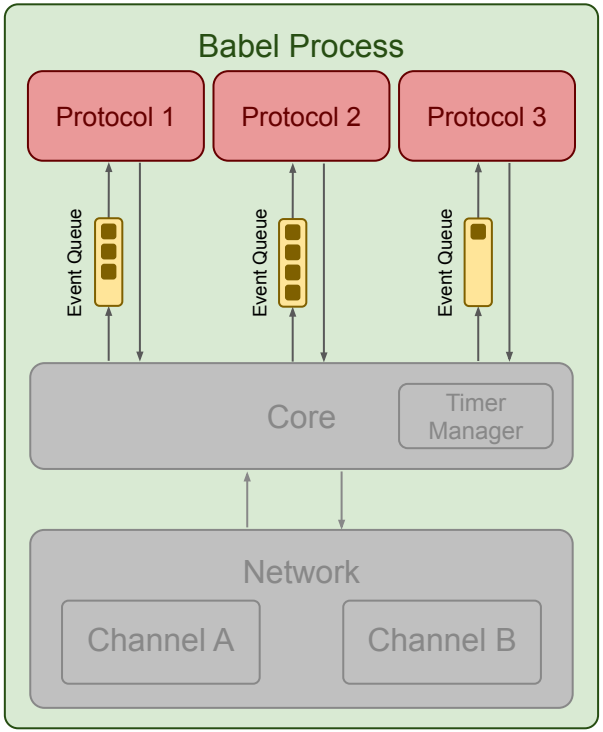

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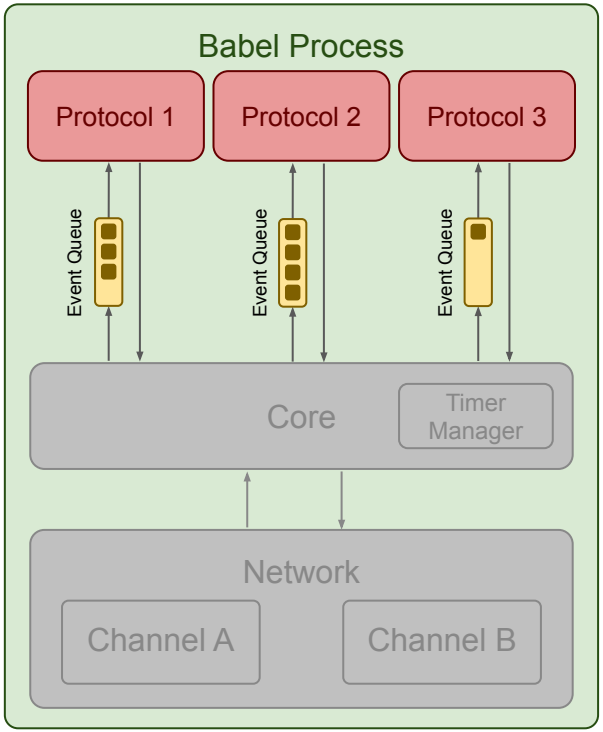

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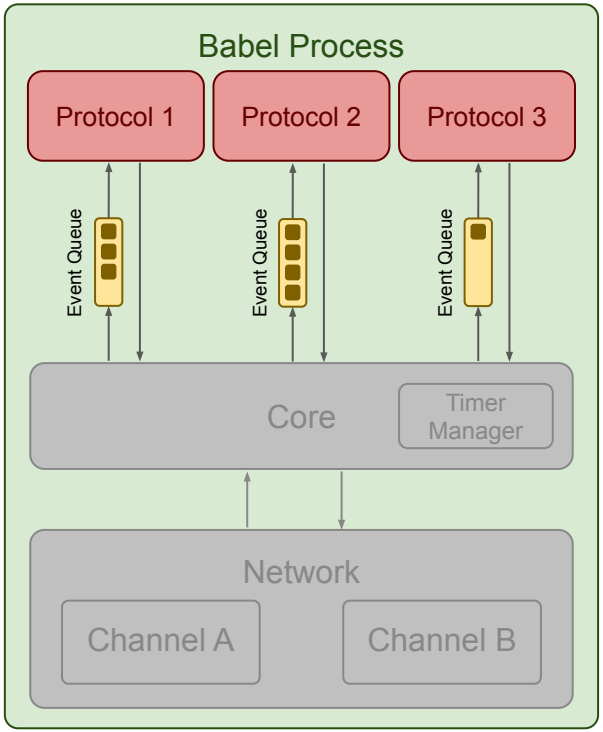

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- **State-machine** that evolves by processing events.
- Communication by **message passing** (no shared state).

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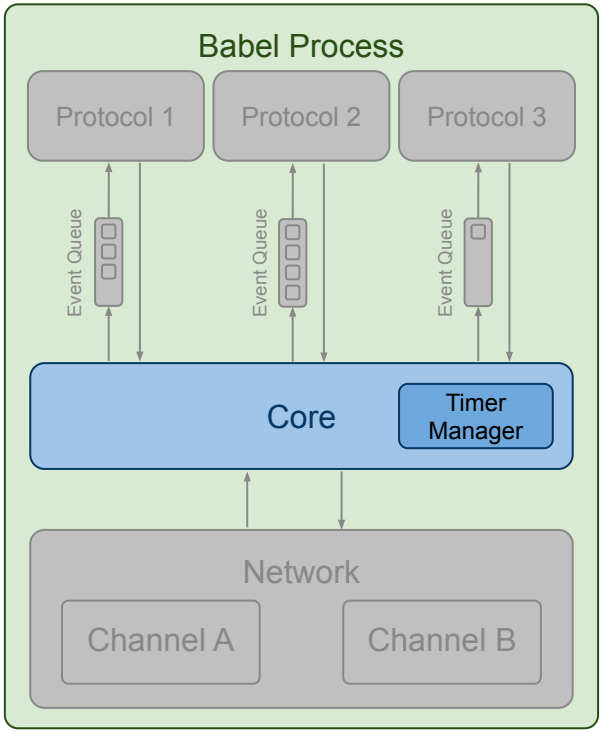

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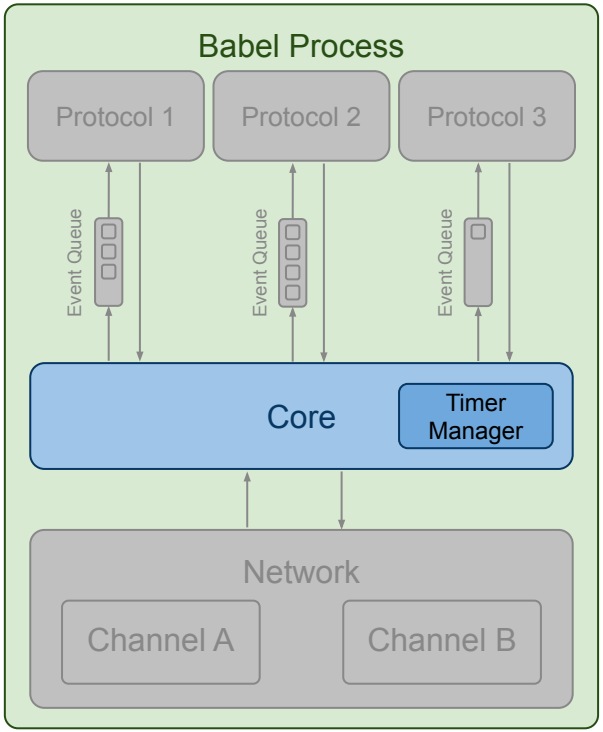

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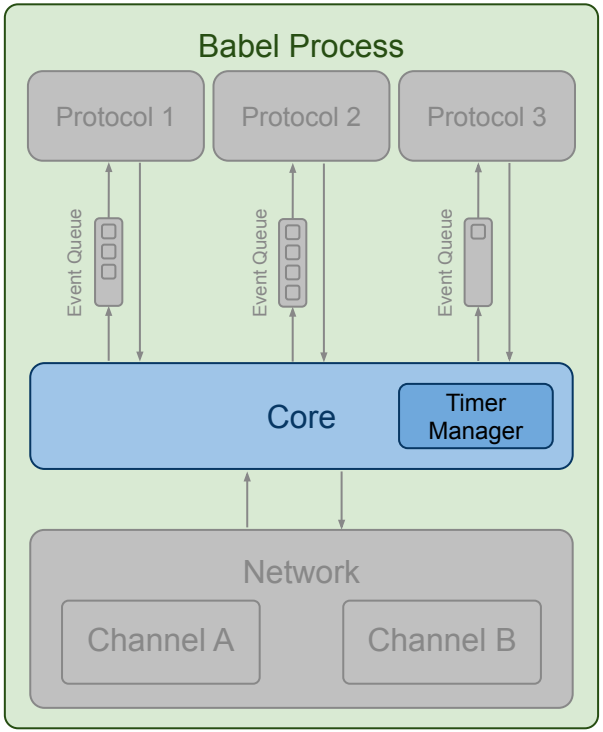

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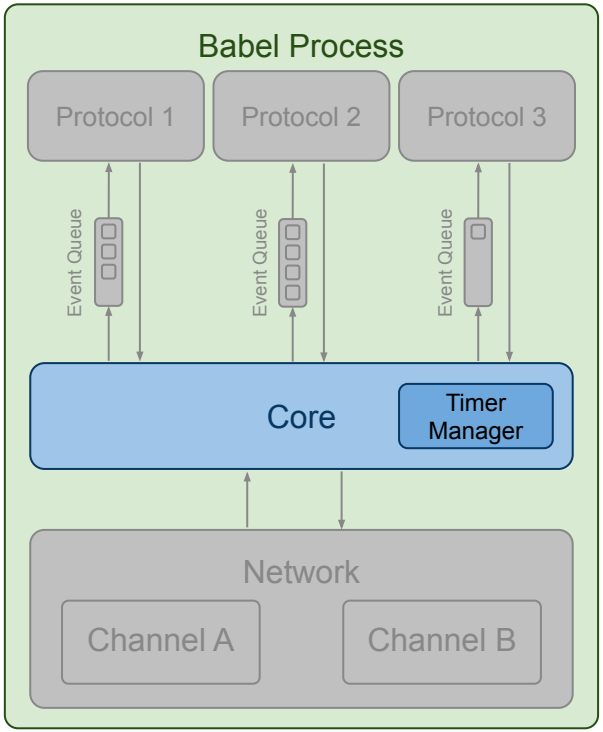

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- Mediates all interactions between protocols.
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  - Delivers outgoing **network messages** from protocols to the network channel and incoming ones to the correct protocol.
  - Tracks **timers** and delivers timer events to protocols.

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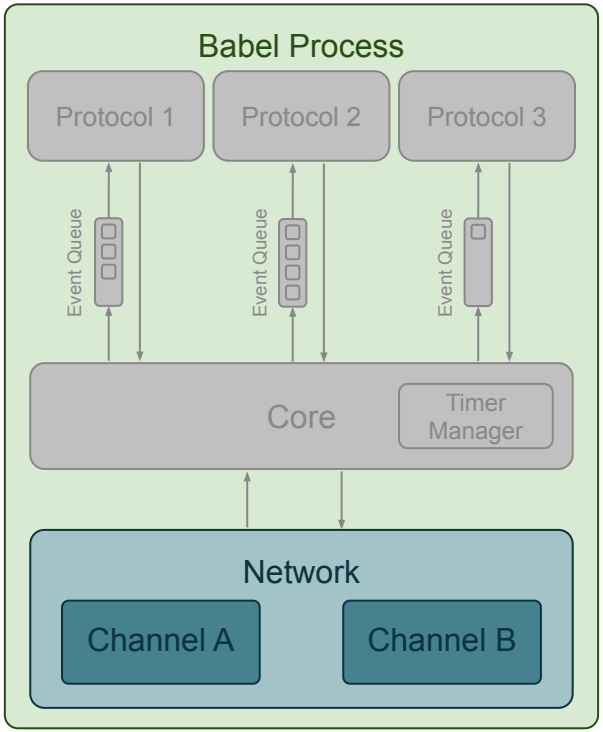

Network channels:

- **Abstract complexity** of dealing with networking.

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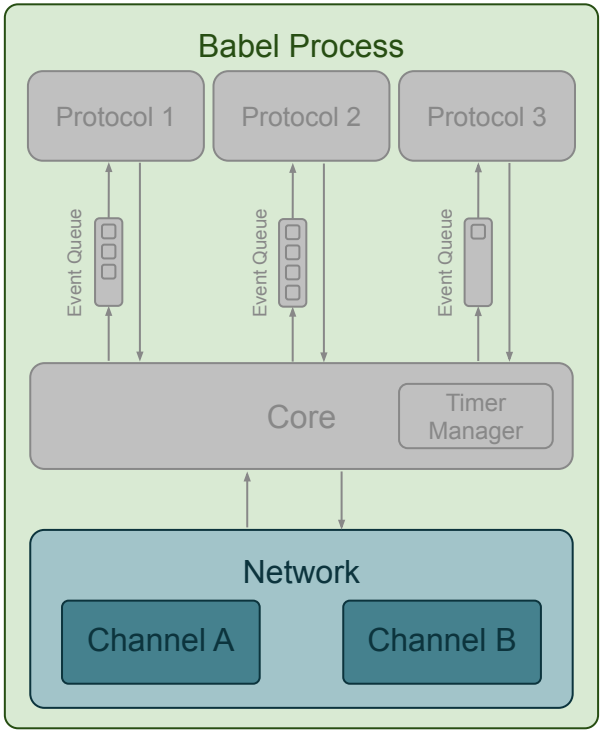

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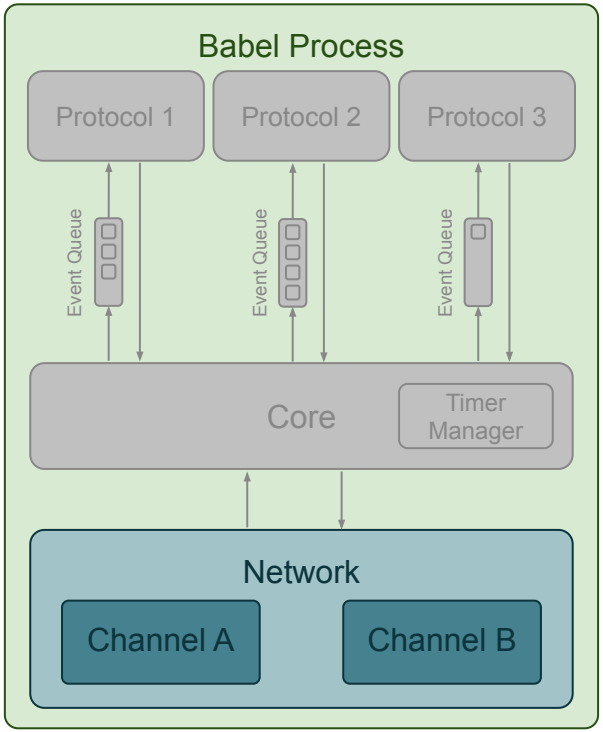

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  - e.g.: explicit and automatic acknowledgement of messages; transparent creation of multiple TCP connections; failure detectors.

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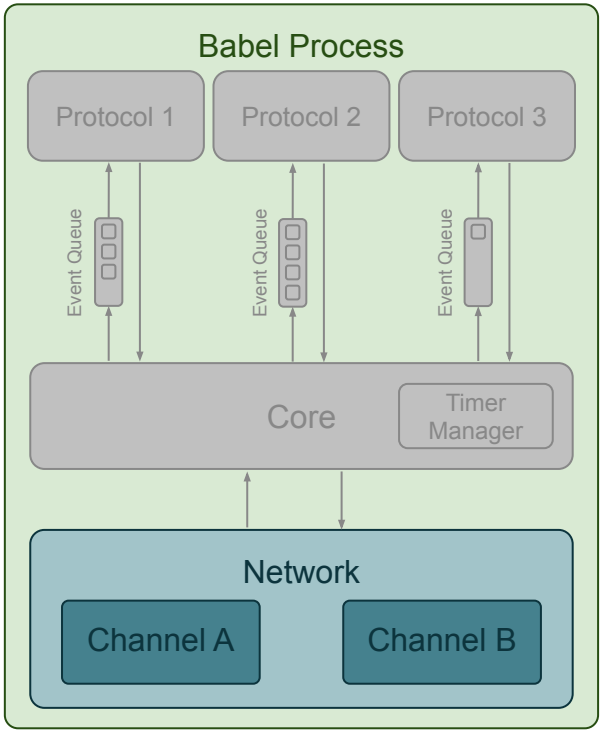

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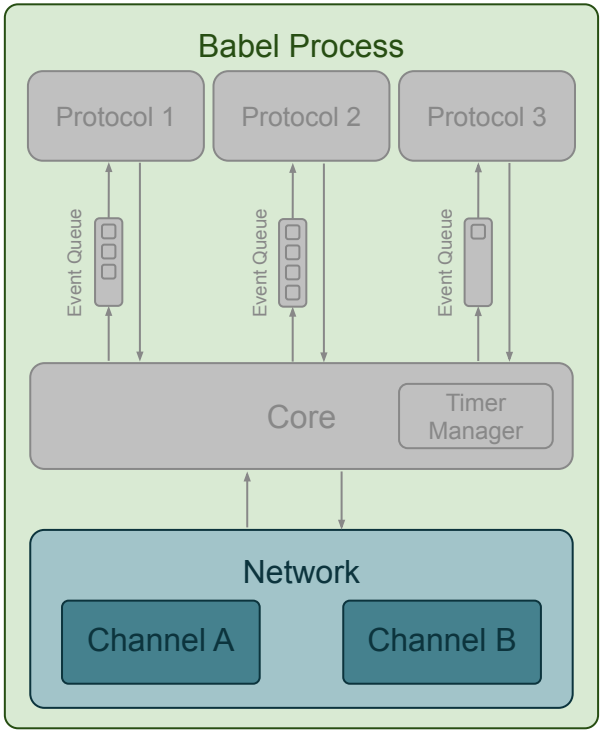

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  - e.g.: explicit and automatic acknowledgement of messages; transparent creation of multiple TCP connections; failure detectors.
- Developers can **create additional channels** that provides **specific abstractions** for their protocols.
- Protocols can use **multiple channels**, channels can be **shared** by multiple protocols.

Babel: API

```
public class HelloProtocol extends GenericProtocol {

  public HelloProtocol() {
    super("Hello", 100);
  }

  public void init (Properties props) {
    ...
    sendMessage(new HelloMsg(), contactNode);
  }

  private void uponHelloMsg(HelloMsg msg, Host from){
    ...
  }
}
```

Protocols extend an abstract Java class

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Protocols extend an abstract Java class

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Implementing protocols consists (mostly) in creating and registering handlers for events

Protocols extend an abstract Java class

Unique identifier for each protocol

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Babel: API

- Protocols handle 3 types of Events:
  - Timers
  - Inter-Protocol Communication
  - Networking

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  - **Timers**
    - Periodic/Timed actions are a common part of distributed applications.
  - Inter-Protocol Communication
  - Networking

Babel: API - Timers

```
public class CounterTimer extends ProtoTimer {

  public static final short ID = 101;
  int counter;

  public CounterTimer(int initValue) {
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  }

  public void decCounter() {
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Can have any internal logic

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public class CountdownProtocol extends GenericProtocol {

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    super("Countdown", 100);
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  @Override
  public void init (Properties props) {
    registerTimerHandler(CounterTimer.ID, this::handleCounter);
    setupPeriodicTimer(new CounterTimer(10), 1000, 300);
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  private void handleCounter(CounterTimer timer, long tId){
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Setup and register handlers for timers

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  - Timers
    - Periodic/Timed actions are a common part of distributed applications.
  - **Inter-Protocol Communication**
    - Distributed applications require multiple different protocols to coordinate.
    - One-to-one **requests/replies**
    - One-to-many **notifications**
  - Networking

Babel: API - Inter-protocol communication

```
public class ViewChange extends ProtoNotification {

  public static final short ID = 101;
  Peer peer;

  public ViewChange(Peer p) {
    super(ID);
    peer = p;
  }
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Extends an abstract Java class

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Babel: API - Inter-protocol communication

Example:

- **Membership Protocol**
  - Keeps a view with the current membership
- **Dissemination Protocol**
  - Requests current membership and subscribes to changes

Babel: API - Inter-protocol communication

```
public class DisseminationProtocol extends GenericProtocol {

  public DisseminationProtocol() { super("Disseminator", 200); }

  public void init (Properties props) {
    subscribeNotification(ViewChange.ID, this::onViewChange);
    registerReplyHandler(ViewReply.ID, this::onViewReply);
    sendRequest(new ViewRequest(), MembershipProtocol.ID);
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  private void onViewReply(ViewReply reply, short from) {...}
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Setup and register handlers

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public class DisseminationProtocol extends GenericProtocol {

  public DisseminationProtocol() { super("Disseminator", 200); }

  public void init (Properties props) {
    subscribeNotification(ViewChange.ID, this::onViewChange);
    registerReplyHandler(ViewReply.ID, this::onViewReply);
    sendRequest(new ViewRequest(), MembershipProtocol.ID);
  }

  private void onViewReply(ViewReply reply, short from) {...}
  private void onViewChange(ViewChange not, short emitter){...}
}
```

Setup and register handlers

Sending requests/replies

Babel: API - Inter-protocol communication

```
public class MembershipProtocol extends GenericProtocol {

  public static final short ID = 300

  public MembershipProtocol() { super("Membership", ID); }

  public void init (Properties props) {
    registerRequestHandler(ViewRequest.ID, this::onViewRequest);
  }

  private void onViewRequest(ViewRequest request, short from) {
    sendReply(new ViewReply(currentView), from);
  }

  private void onConnectionEstablished(Peer peer){
    triggerNotification(new ViewChange(peer));
  }
}
```

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Replies to received requests

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Replies to received requests

Notifies all subscribers

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Replies to received requests

Notifies all subscribers

No destination protocol required

Babel: API

- Protocols handle 3 types of Events:
  - Timers
    - Periodic/Timed actions are a common part of distributed applications.
  - Inter-Protocol Communication
    - Distributed applications require multiple different protocols to coordinate.
    - One-to-one requests/replies
    - One-to-many notifications
  - Networking

Babel: API

- Protocols handle 3 types of Events:
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  - Inter-Protocol Communication
    - Distributed applications require multiple different protocols to coordinate.
    - One-to-one requests/replies
    - One-to-many notifications
  - **Networking**
    - Distributed application need networking to be distributed.

Babel: API - Networking

```
public class PingMsg extends ProtoMessage {
  public final static short MSG_ID = 401;
  private final long timestamp;

  public PingMsg(long timestamp) {
    super(MSG_ID);
    this.timestamp = timestamp;
  }

  public static ISerializer<PingMsg> serializer = new ISerializer<>() {
    public void serialize(PingMsg msg, ByteBuf out) {
      out.writeLong(msg.timestamp);
    }

    public PingMsg deserialize(ByteBuf in){
      return new PingMsg(in.readLong());
    }
  }
}
```

Network messages extend generic class

Babel: API - Networking

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Can have any internal logic

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Require a serializer to encode and decode

Babel: API - Networking

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Network messages extend generic class

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Require a serializer to encode and decode

Babel: API - Networking

Example:

- **Ping Pong Protocol**
  - Chooses a random peer to send a Ping message
  - Peer responds with Pong message
  - Repeat

Babel: API - Networking

```
public class PingPongProto extends GenericProtocol {
  List<Host> peers;

  public PingPongProto() { super("PingPong", 400); }

  public void init (Properties props) {
    int cId = createChannel(TCPChannel.Name, props);
    registerMessageSerializer(cId, PingMsg.ID, PingMsg.serializer);
    registerMessageHandler(cId, PingMsg.ID, this::uponPing);
    registerChannelEventHandler(cId, OutConnUp.EVENT_ID,
        this::uponOutConnUp);
    openConnection(random(peers));
  }
}
```

Babel: API - Networking

Create channel

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Create channel

Register serializer for each message

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Create channel

Register serializer for each message

Register handler for each message

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Create channel

Register serializer for each message

Register handler for each message

Register other channel events

Babel: API - Networking

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```

Create channel

Register serializer for each message

Register handler for each message

Register other channel events

Create connections

Babel: API - Networking

```
public class PingPongProto extends GenericProtocol {

  private void uponOutConnUp(OutConnectionUp ev, ...){
    sendMessage(new PingMsg(currTime), ev.getPeer());
  }

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Handle channel events

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Handle channel events

Send messages

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Handle channel events

Send messages

Handle received messages

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Handle channel events

Send messages

Handle received messages

Open/close connections

Babel: Summary

- **Developers** only implement **handlers for events**, and register them.
- Implementation **closely matches** typical algorithm specification (**pseudo-code**).
- **Shields developers** from the complexities of concurrency, multiplexing and networking
- Abstractions are sufficiently **generic** to support a wide variety of algorithms.
- Capable of supporting **production-ready performant** implementations.

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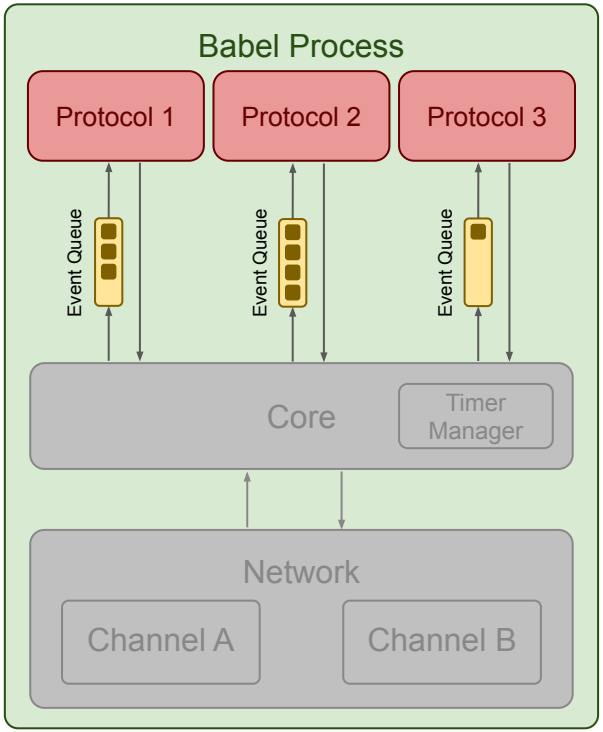
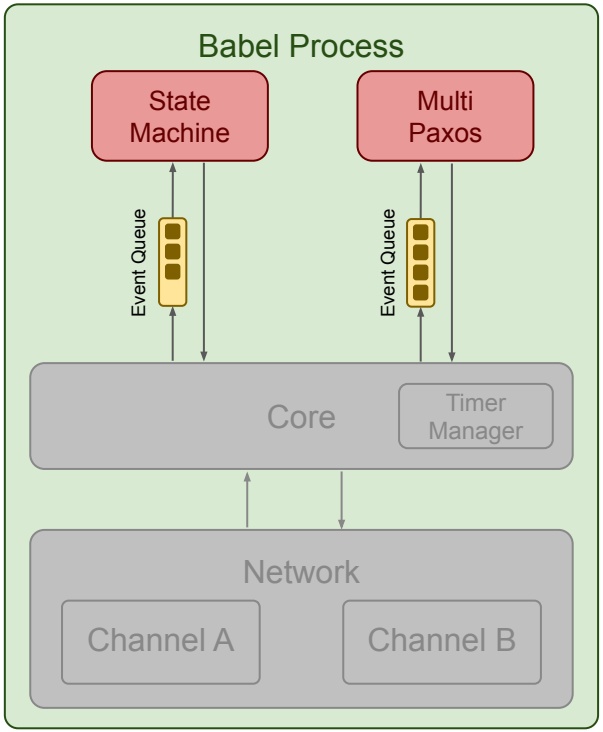
Class Example - MultiPaxos



Two Protocols

- State Machine
- MultiPaxos

Class Example - MultiPaxos



Two Protocols

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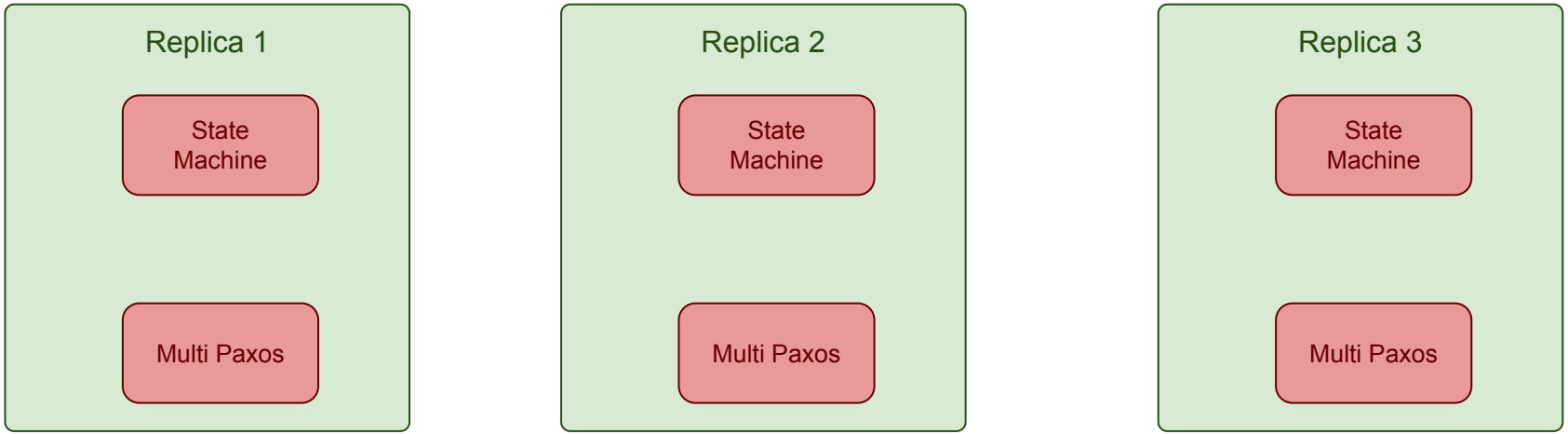

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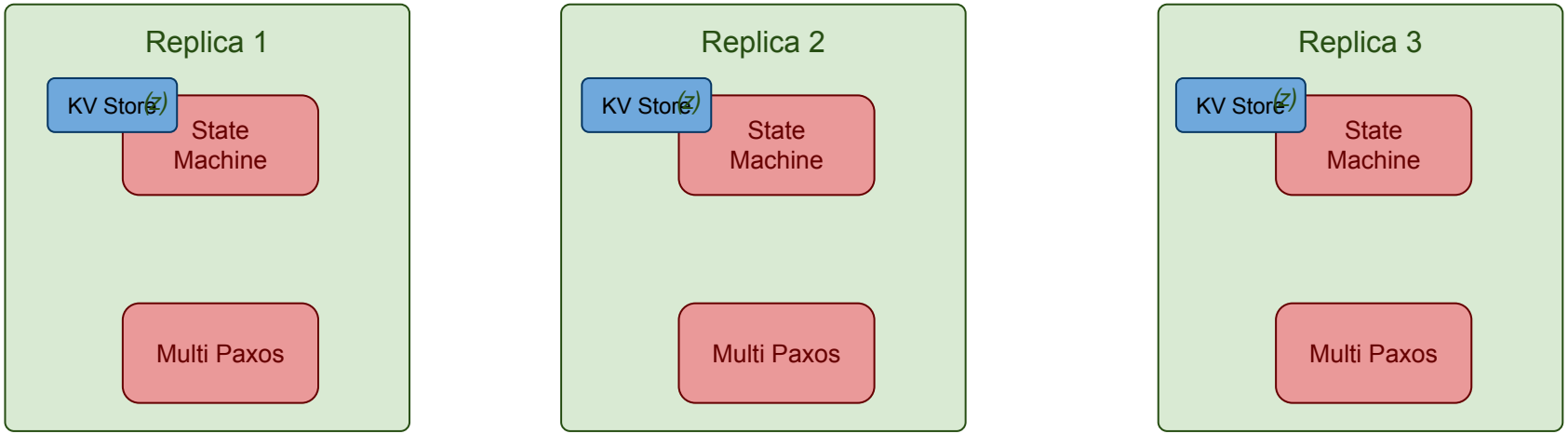

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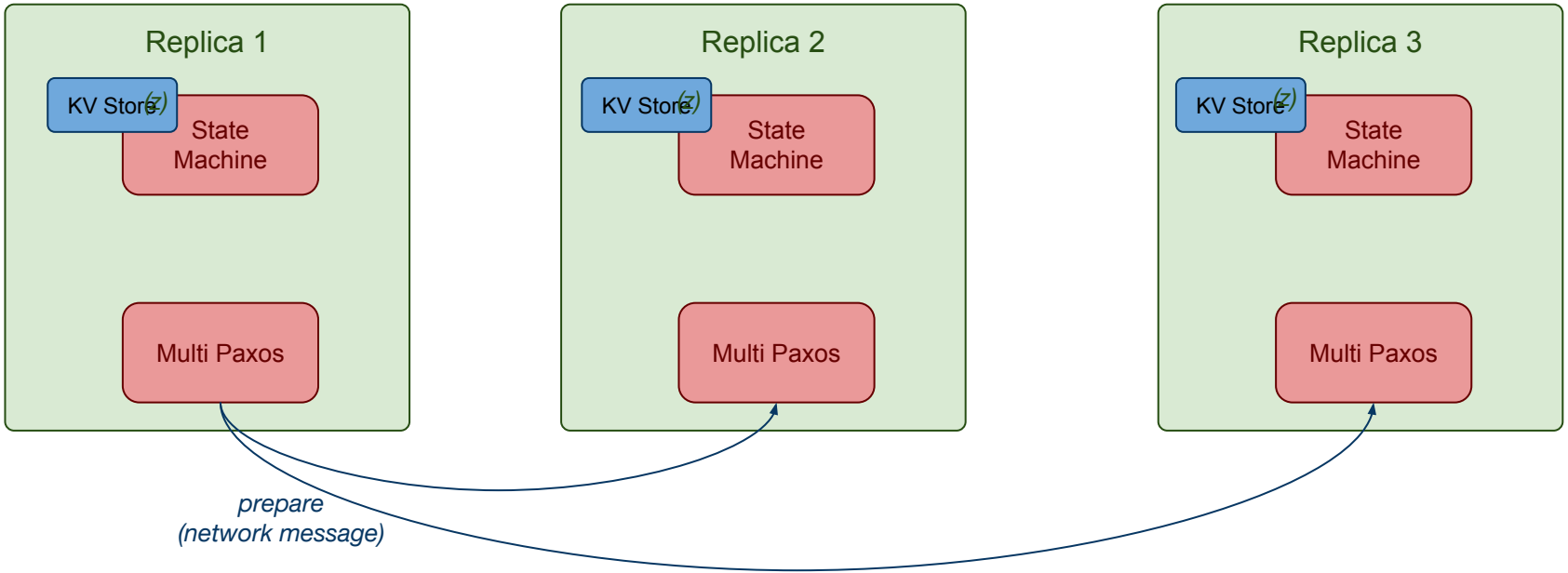

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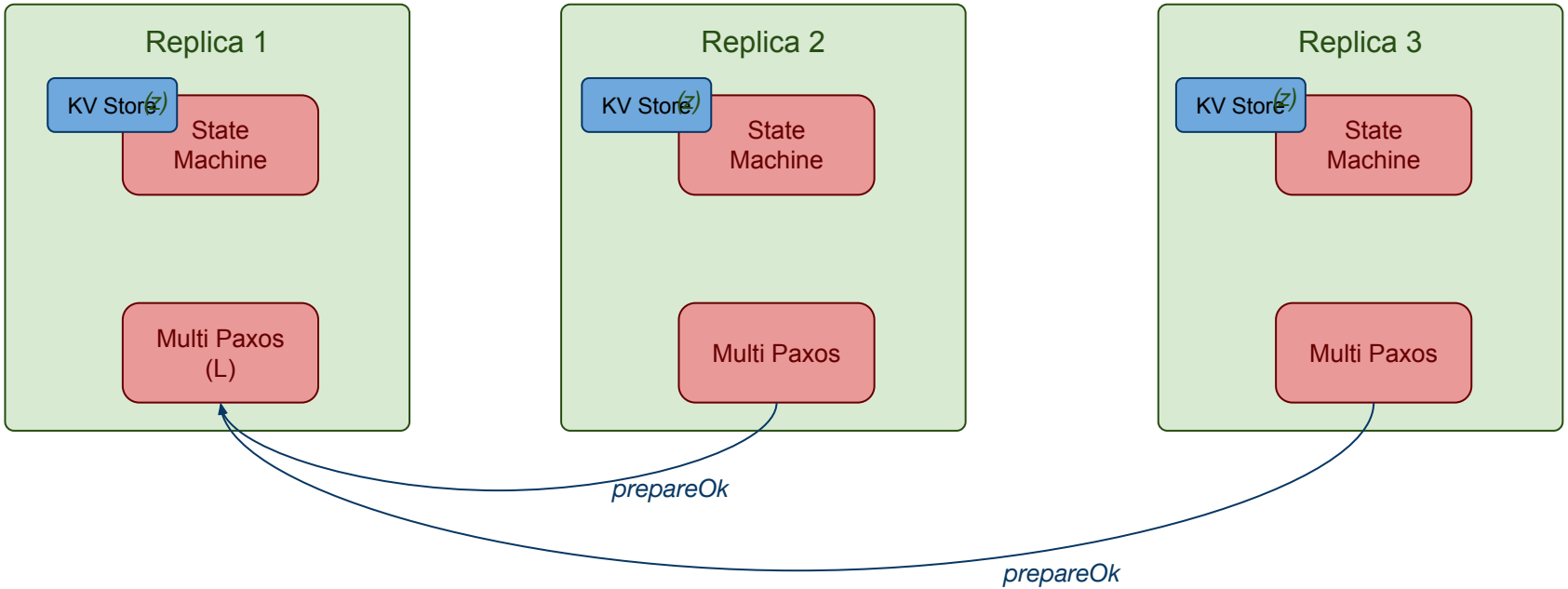

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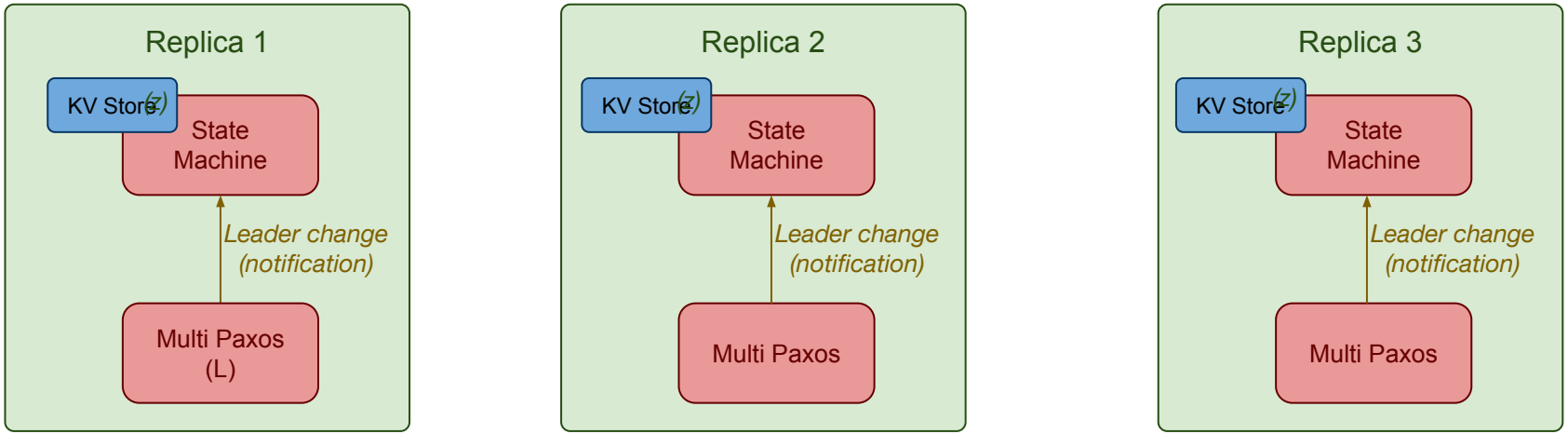

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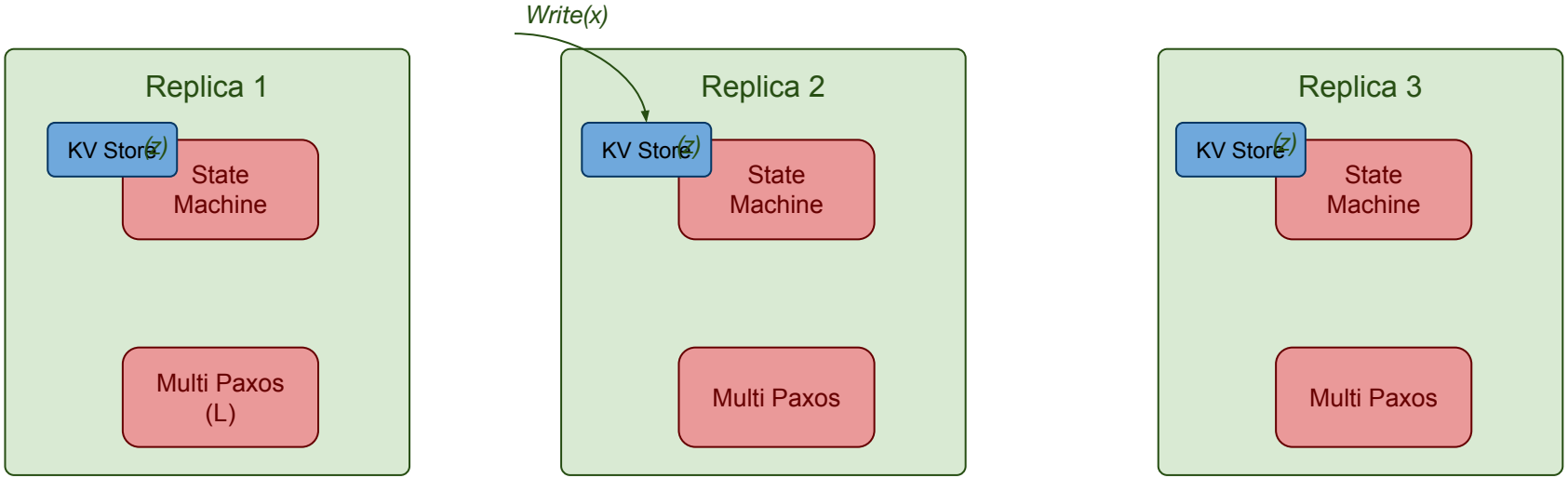

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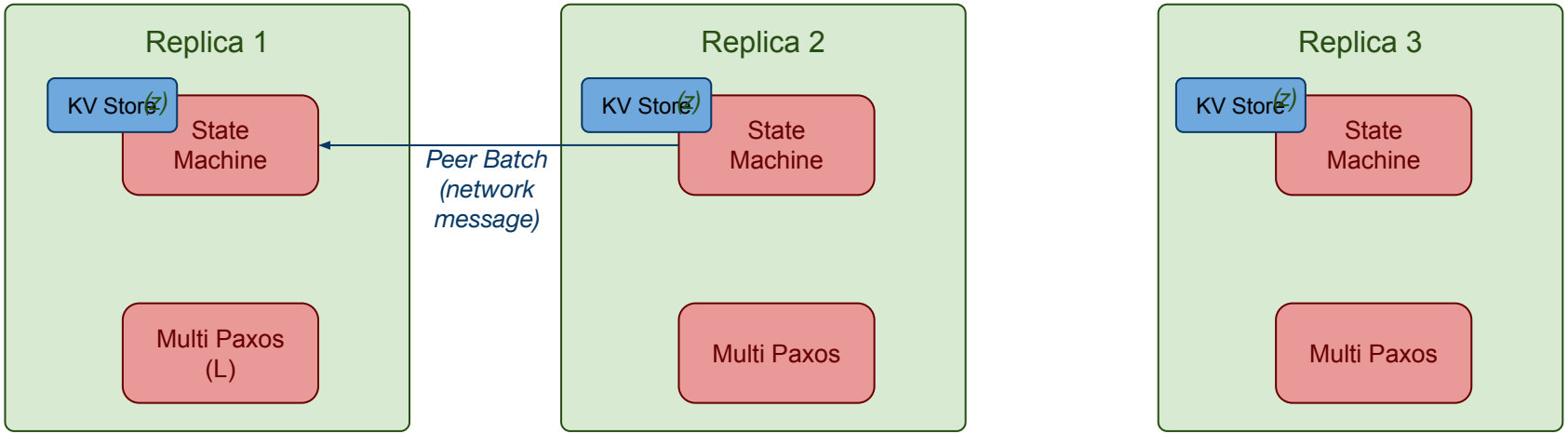

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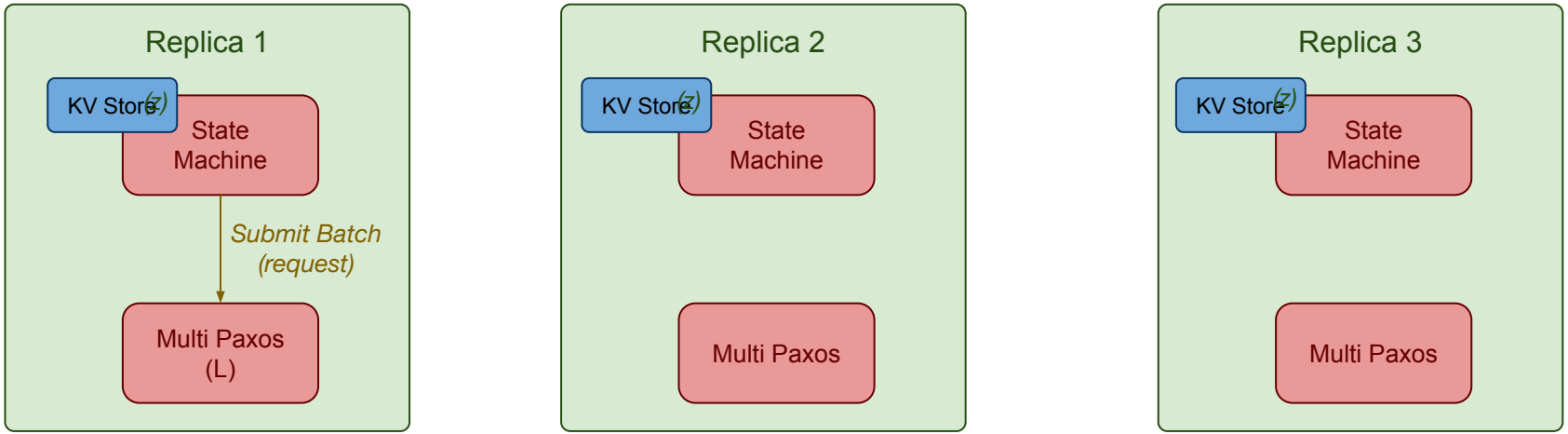

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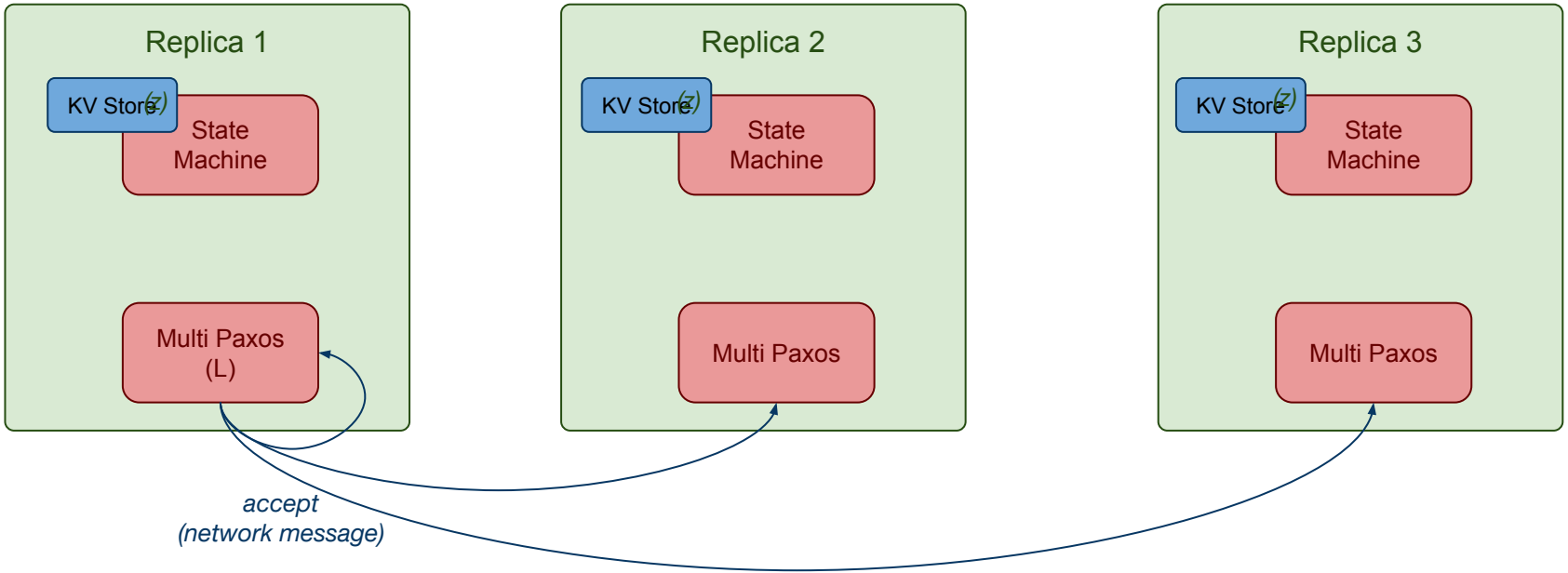

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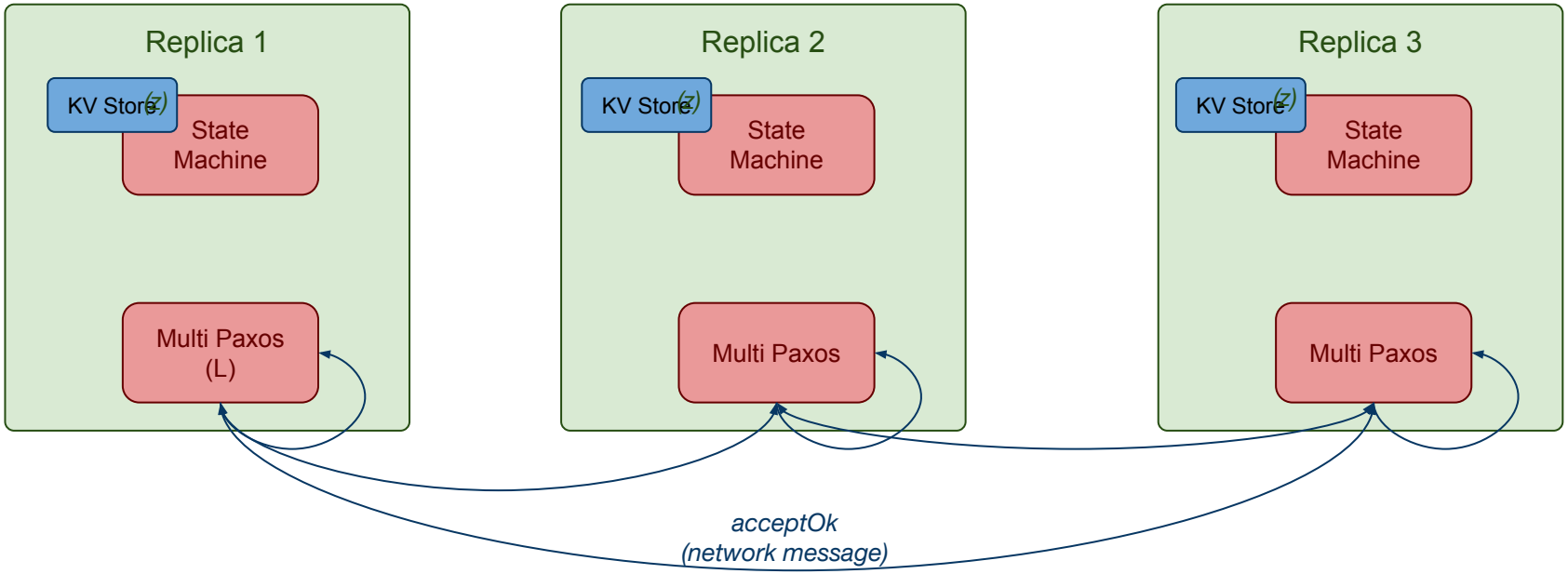

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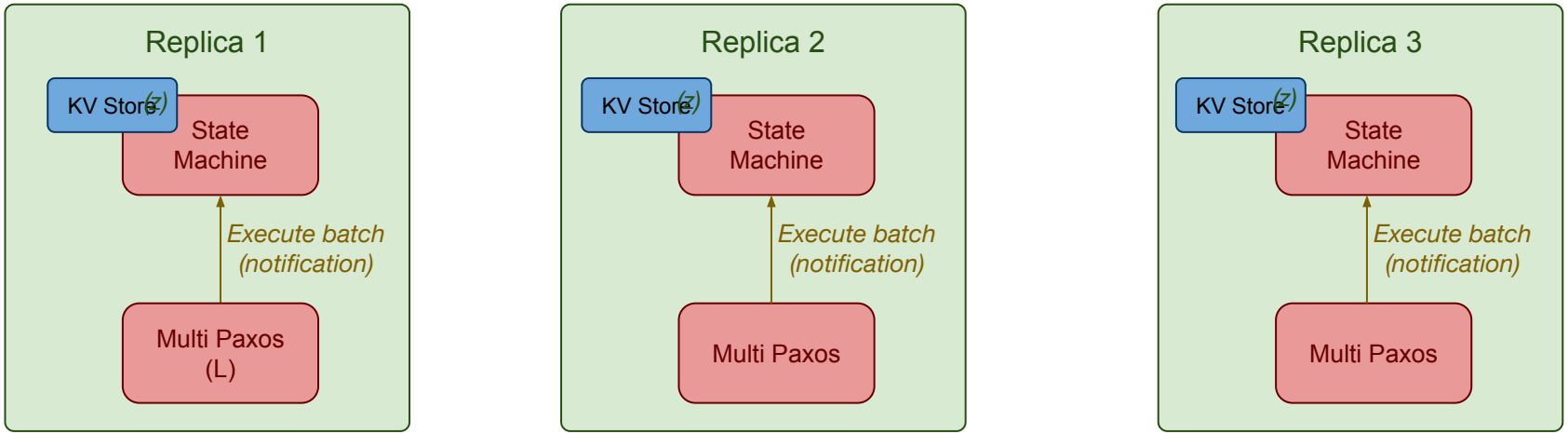

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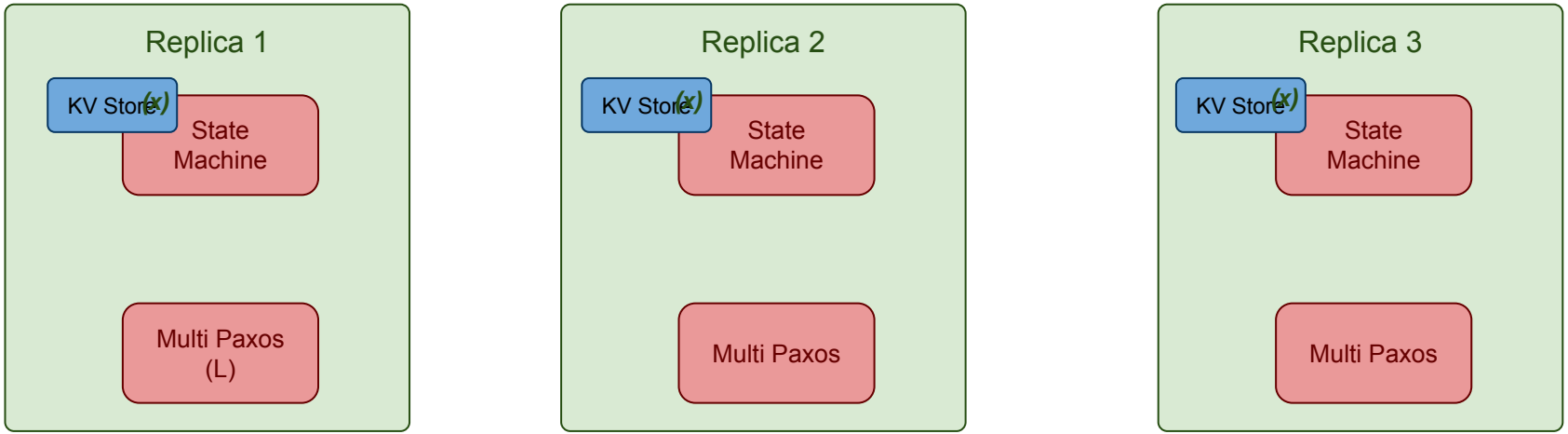

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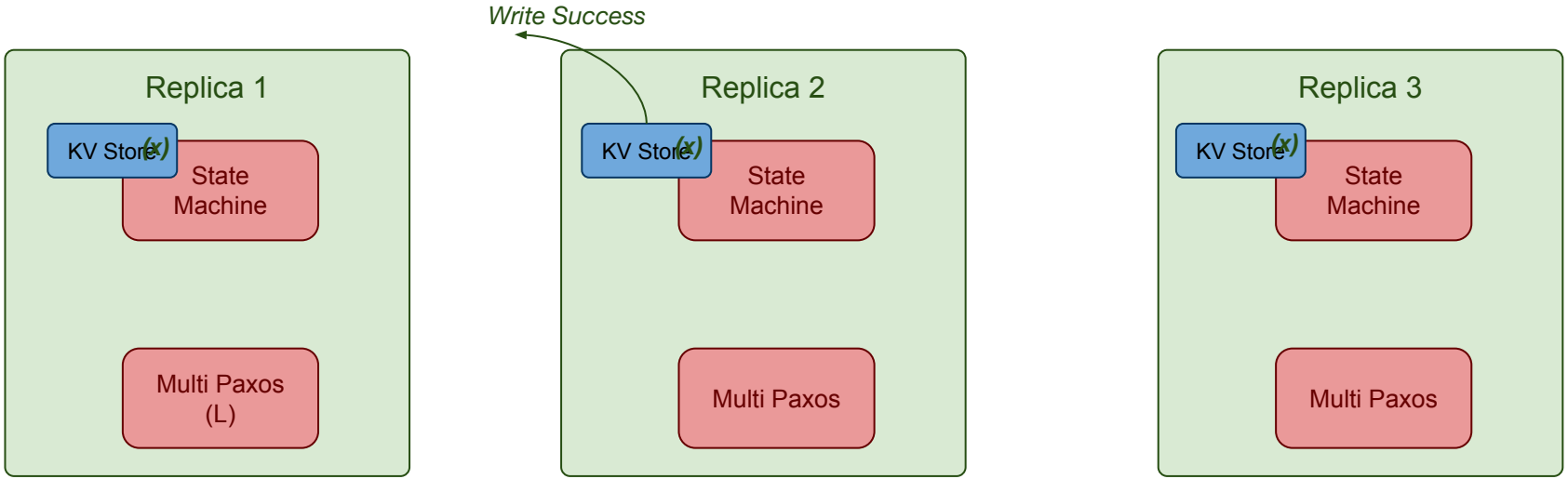

Babel: A framework for developing performant and dependable distributed protocols

Pedro Fouto, Pedro Ákos Costa,
Nuno Preguiça, João Leitão

SRDS 2022

https://github.com/pfouto/babel-core
https://github.com/pedroAkos/babel-case-studies

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