Message Passing Concurrency

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Agenda

- Agents motivations
- What are Agents
- Agents vs Actors
- Agents patterns

Agent motivations

- You can manage **shared data** and resources **without locks**.
- You can easily follow the **SRP**, because each **agent** can be designed to **do only one thing**.
- It encourages a "pipeline" model of programming with "producers" sending messages to decoupled "consumers“
- It is straightforward to **scale**
- Errors can be handled gracefully, because the decoupling means that agents can be created and destroyed without affecting their clients.

Agent-based concurrency

Programs **composed** from agents

- Agents can be viewed as “running” objects

Agents **exchange** messages

- Receive message and react
- Trigger event when work is done

Reactive system

- Handle inputs while running
- Emit results while running

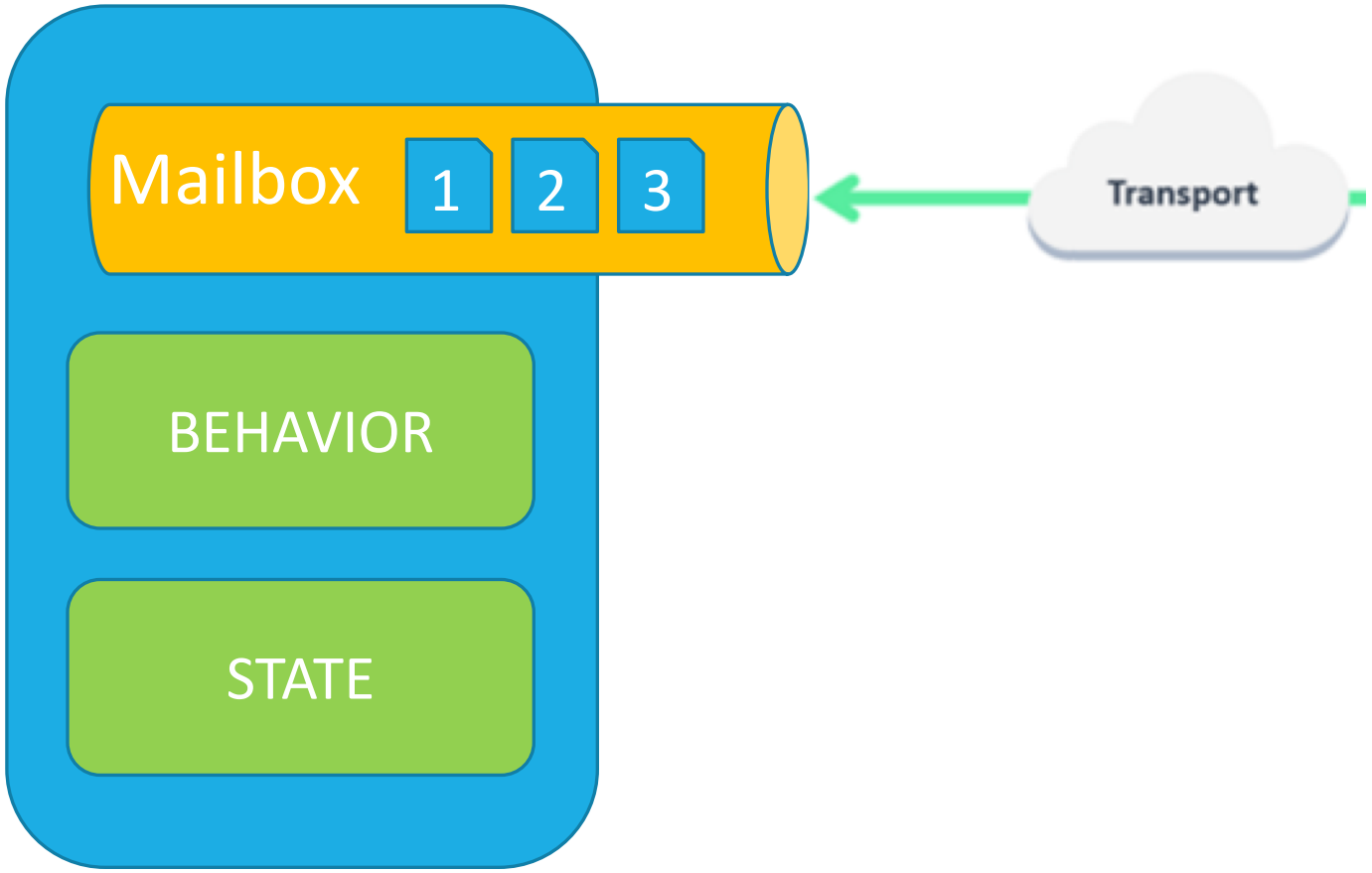
Agent is a single and independent unit of computation

Message-Driven

What are Agents

- Communication between agents done by **sending message**
- The messages are put on a **queue** for each agent
- Each agent process **one message** at time

Message Passing based concurrency



- Processing
- Storage – State
- Communication only by messages
- Share Nothing
- Message are passed by value
- Lightweight object
- Running on it’s own thread
- No shared state
- Messages are kept in mailbox and processed in order
- Massively scalable and lightening fast because of the small call stack

Share Nothing, Async Message Passing

- Encourages shared-nothing process abstractions
  - mutable state - private
  - shared state - immutable
- Asynchronous message passing
- Pattern matching

Declaring messages

- Easier to reason about
- Higher abstraction level
- Easier to avoid
  - Race conditions
  - Deadlocks
  - Starvation
  - Live locks
- Distributed computing

What is an Actor?

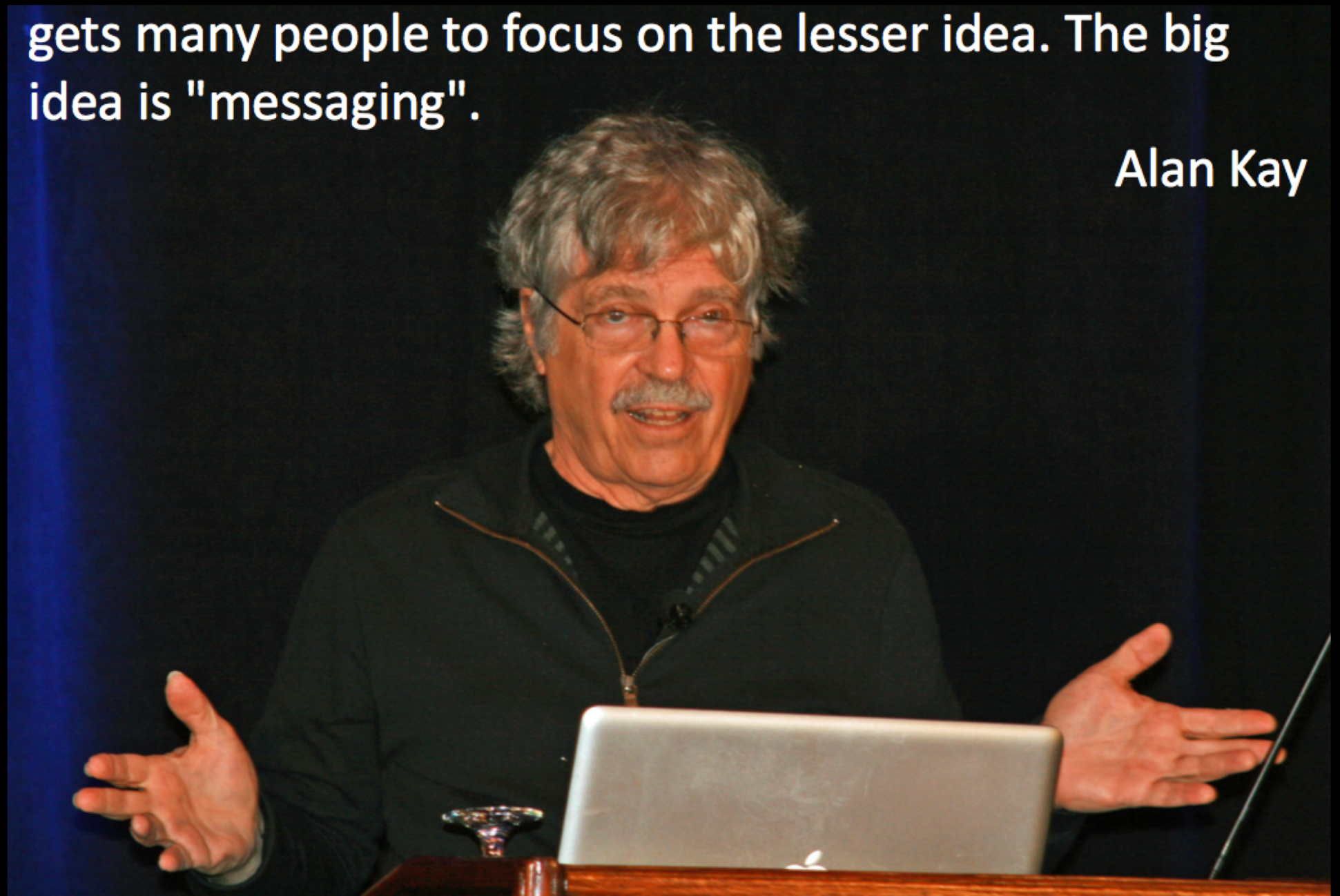
- **Share Nothing**
- **Message are passed by value**
- Light weight processes/threads communicating through messaging
- Communication only by messages
- Lightweight object
- Processing
- Storage – State
- Running on it’s own thread.
- Messages are buffered in a “mailbox”

Agents vs Actors

- Agent work in process
- Actors work also out of process
- Agent messages pass by reference
- Actor messages always serialized before sent

I'm sorry that I coined the term "objects", because it gets many people to focus on the lesser idea. The big idea is "messaging".

Alan Kay



Simple agent in F#

Receive message and say “Hello”

```
let hello = Agent.Start(fun agent -> async {
  while true do
    let! name = agent.Receive()
    printfn "Hello %s"  name
    do! Async.Sleep 500 })

hello.Post(“World!")
```

- Single instance of the body is running
- Waiting for message is asynchronous
- Messages are queued by the agent

Mutable and immutable state

Mutable state

- Accessed from the body
- Used in loops or recursion
- Mutable variables (ref)
- Fast mutable collections

Immutable state

- Passed as an argument
- Using recursion (**return!**)
- Immutable types
- Can be returned from the agent

```
Agent.Start(fun agent -> async {
  let names = ResizeArray<_>()
  while true do
    let! name = agent.Receive()
    names.Add(name) })
```

```
Agent.Start(fun agent ->
  let rec loop names = async {
    let! name = agent.Receive()
    return! loop (name::names) }
 loop [])
```

Declaring messages

Agents handle multiple messages

- Message type using discriminated union

```
type CacheMessage<'T> =
  | Add of string * 'T
  | Get of string * AsyncReplyChannel<option<'T>>
  | Reset
```

Safety guarantees

- Agent will be able to handle all messages

Agent-based programming

Program consists of agents

- **Lightweight** – can create lots of them
- Written using **asynchronous** workflows

Agents communicate via messages

- Communication is **thread-safe**
- Messages are **queued**

Enables parallelism

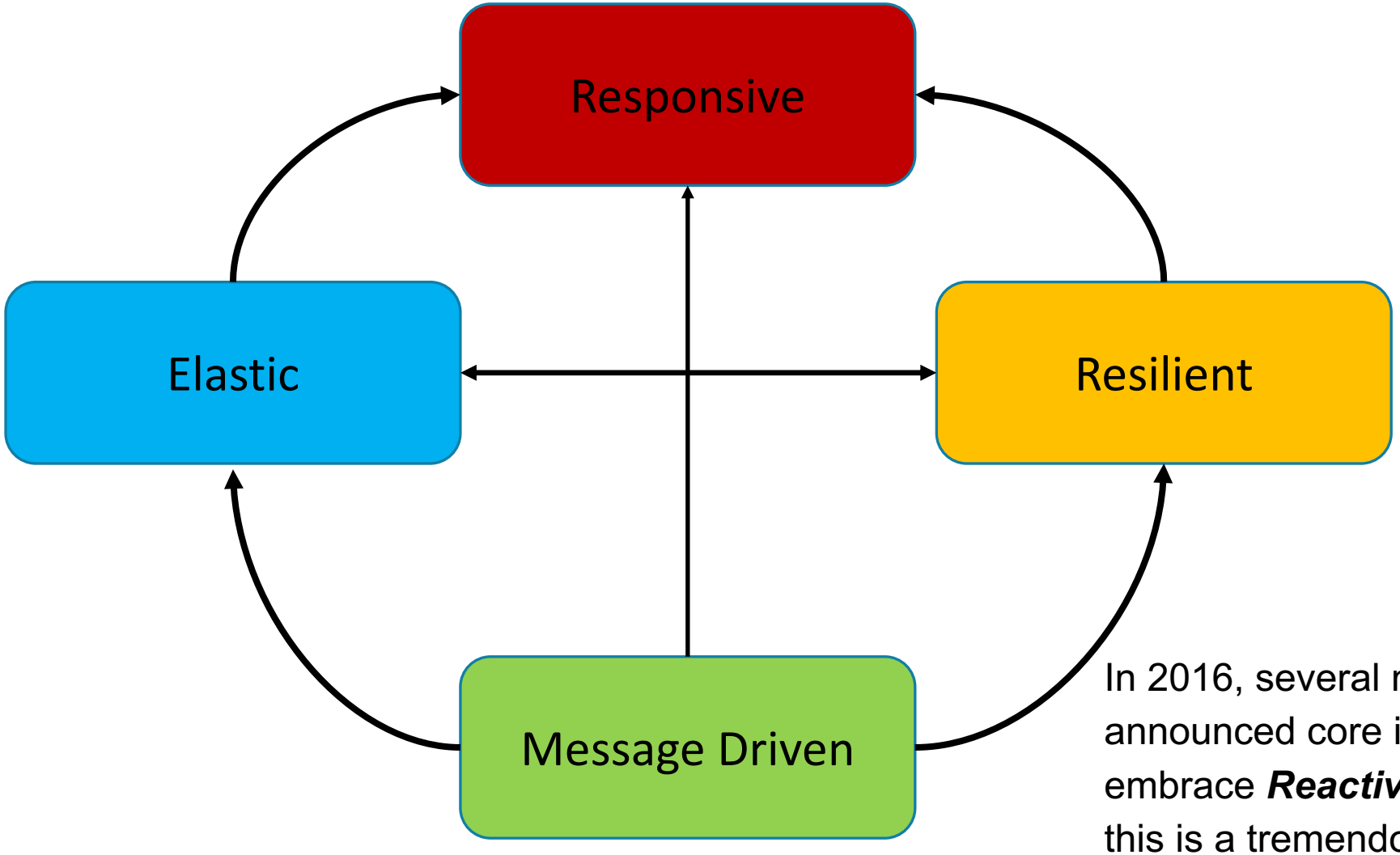
- **Different agents** vs. **multiple instances**

Actors / Agents

- React to received messages by executing a behavior function
  - can only change the state of the actor itself
  - can send messages to other actors
- Actors never share state and thus never need to compete for locks for access to shared data

- Actors exchange data by sending **immutable** messages
- Messages are sent asynchronously
- Actors do not block waiting for responses to their messages

Reactive Manifesto



In 2016, several major vendors have announced core initiatives to embrace ***Reactive Programming*** this is a tremendous validation of the problems faced by companies today.

http://www.reactivemanifesto.org

Reactive Manifesto & Actor Model

Responsive	Event Driven
Message-Driven	Communication by messages
Resilient	Fault tolerant by Supervision
Elastic	Clustering and Remoting across multiple machines

Immutability OR Isolation

F#

```
let printerAgent = MailboxProcessor.Start(fun inbox->
    let list = new List<string>()
    // the message processing function
    let rec messageLoop() = async{
        // read a message
        let! msg = inbox.Receive()
        // process a message
        printfn "message is: %s" msg
        // loop to top
         list.Add(msg)
        return! messageLoop()
        }
    // start the loop
    messageLoop()
    )
```

Send message to agent

```
printerAgent.Post "hello"
printerAgent.Post "hello again"
printerAgent.Post "hello a third time"
```

Agent-based architecture

Lots of things going on!

- How to keep a big picture?

Using loosely coupled connections

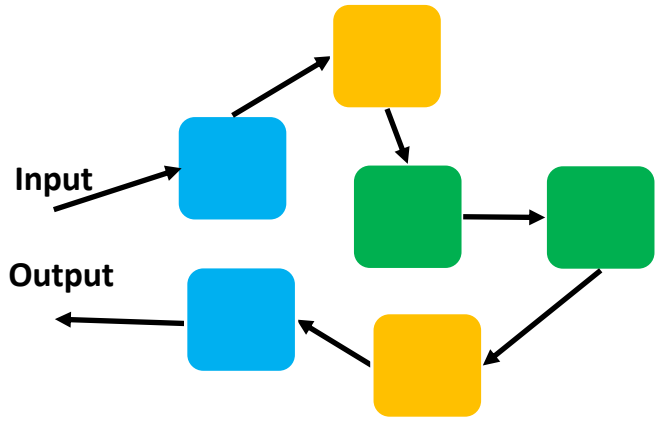
- Agents don’t reference each other directly

Common ways of organizing agents

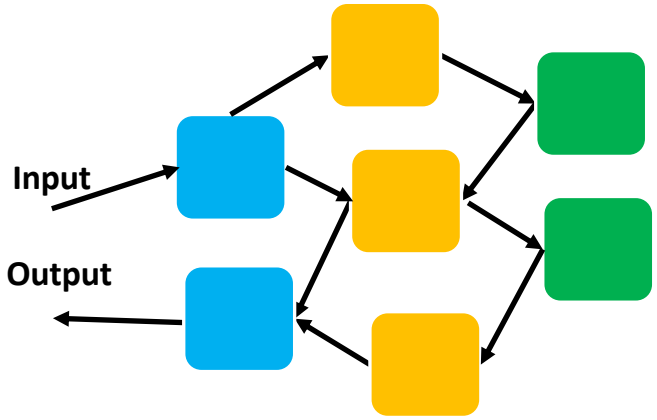
- **Worker agent** – Single agent does work in background
- **Layered network** – Agent uses agents from lower level
- **Pipeline processing** – Step-by-step processing

Comparison between Sequential, Task-based and Message passing programming

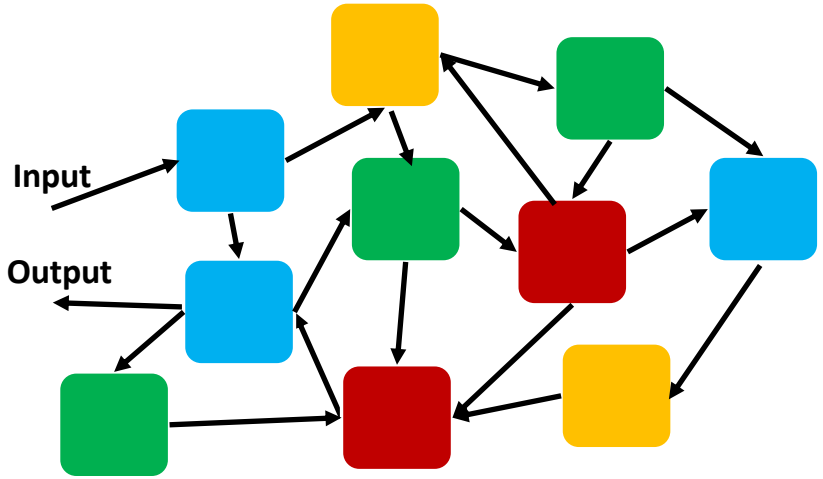
Sequential Programming



Task-Based Programming



Message-Passing Programming



Connecting agents

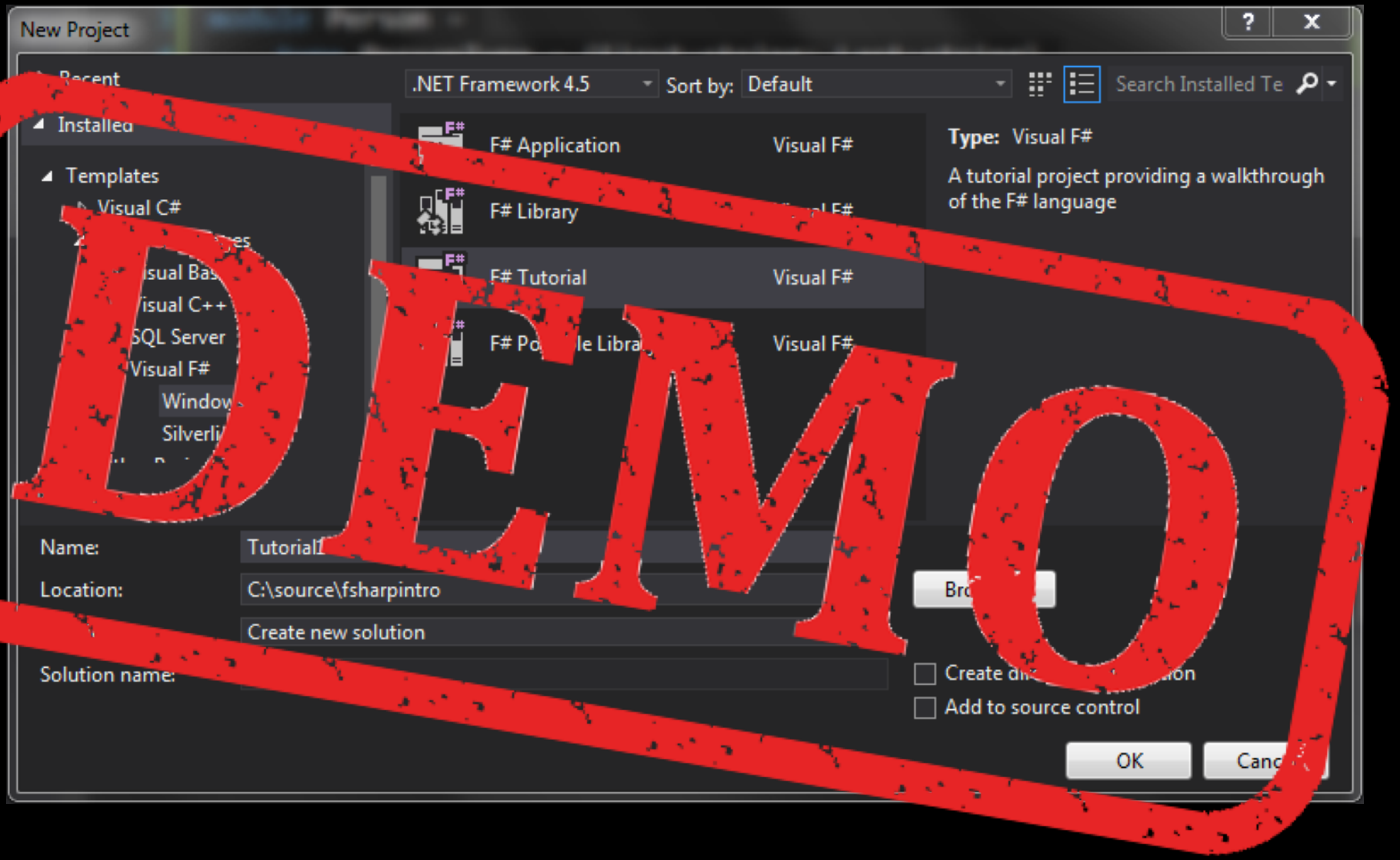
Applications consists of numerous agents

Agents communicate by sending messages

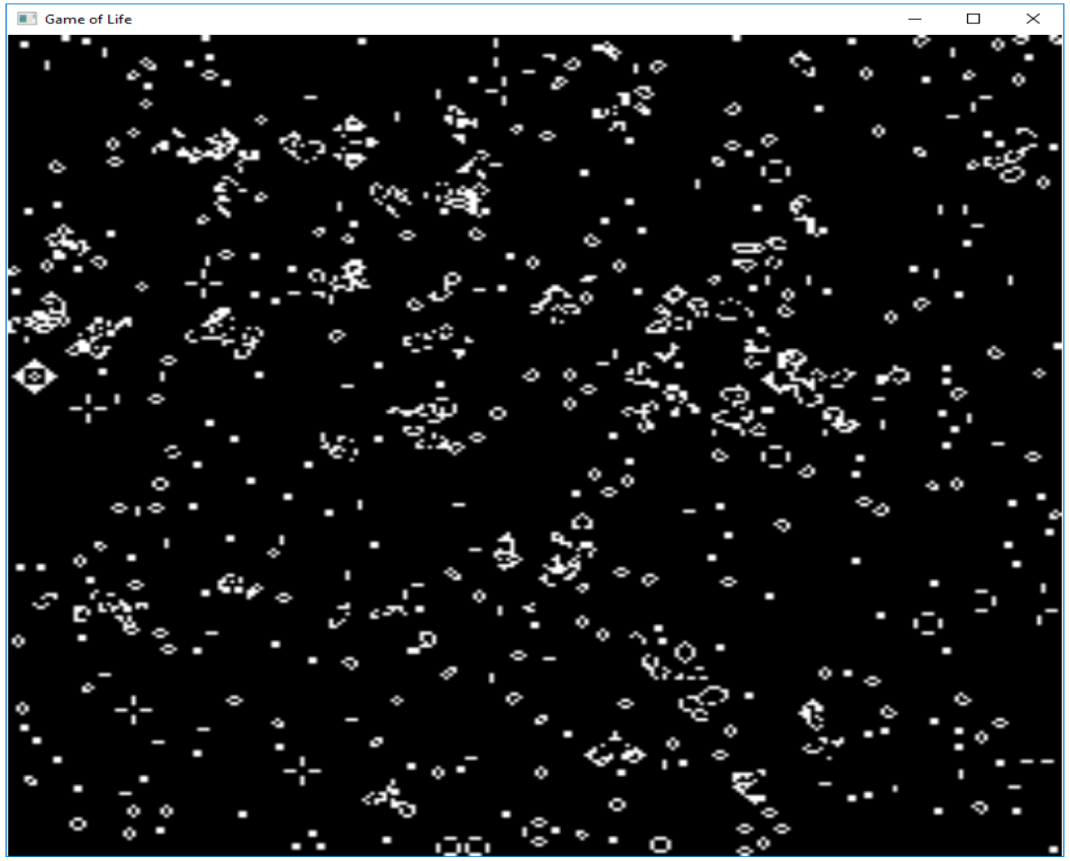
- Direct references are wrong!
- Difficult to follow, reuse and reconfigure

Decoupling of agents

- Expose events instead of sending messages
- Connect agents when creating them
- Use agent repository for dynamic configuration


New Project
.NET Framework 4.5
Sort by:
Default
Search Installed Te
Installed
Templates
Visual C#
Visual C++
SQL Server
Visual F#
Silverli
F# Application
Visual F#
F# Library
F# Tutorial
Visual F#
Visual F#
Type: Visual F#
A tutorial project providing a walkthrough of the F# language
Name:
Tutorial1
Location:
C:\source\fsharpintro
Create new solution
Solution name:
Add to source control
OK
DEMO

Game of Life



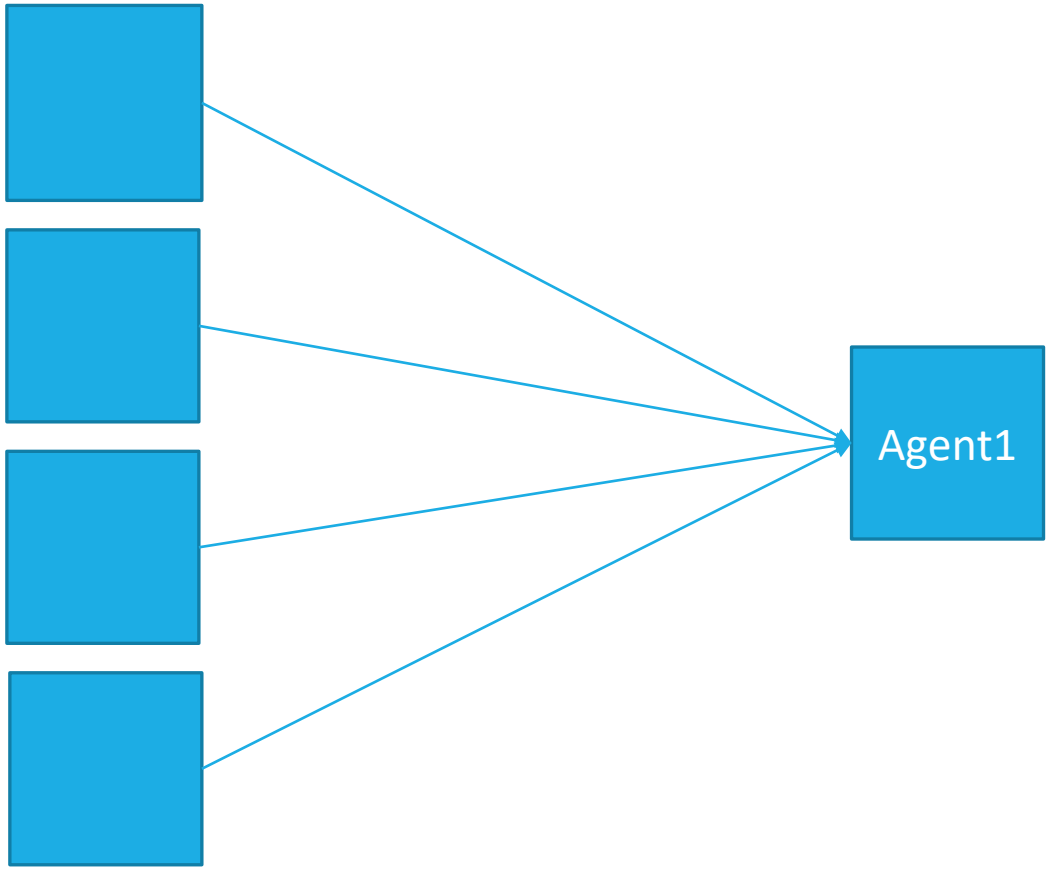
The Game of Life rules:

- Each cell with one or no neighbors dies, as if by solitude.
- Each cell with four or more neighbors dies, as if by overpopulation.
- Each cell with two or three neighbors survives.
- Each cell with three neighbors becomes populated (maximum).

Agent Patterns

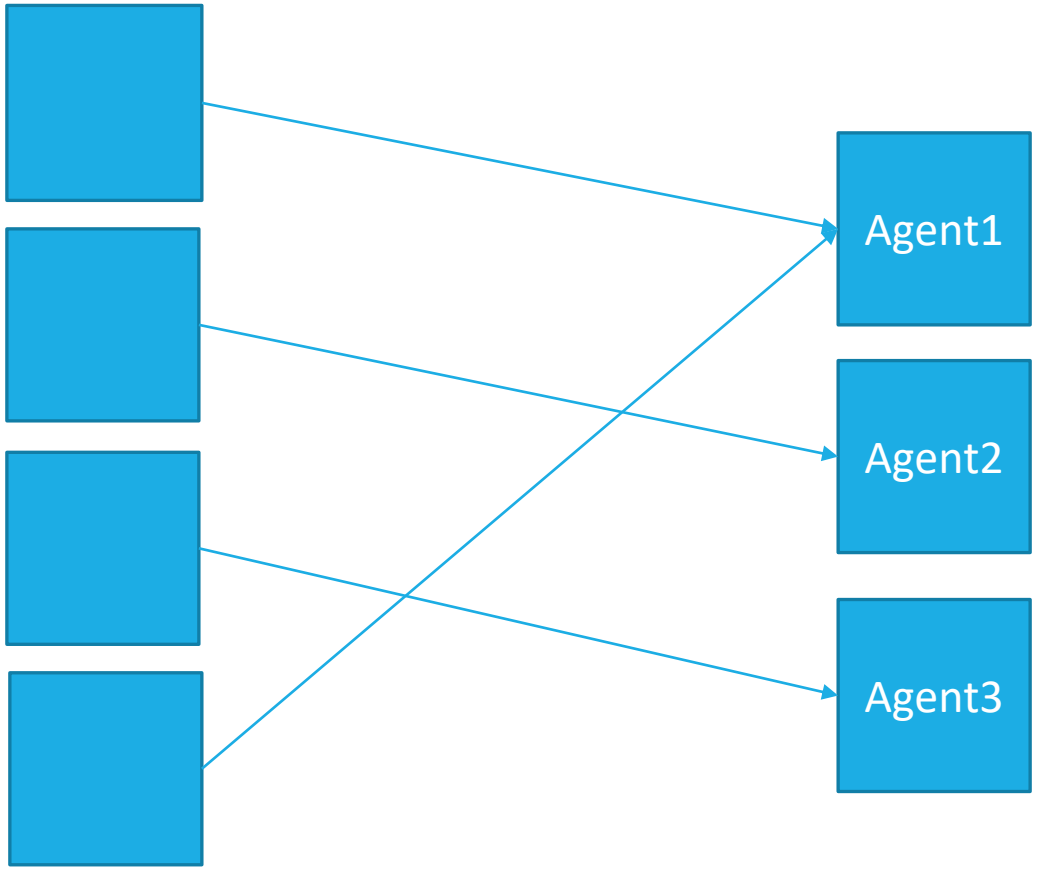
Agent patterns

Singleton



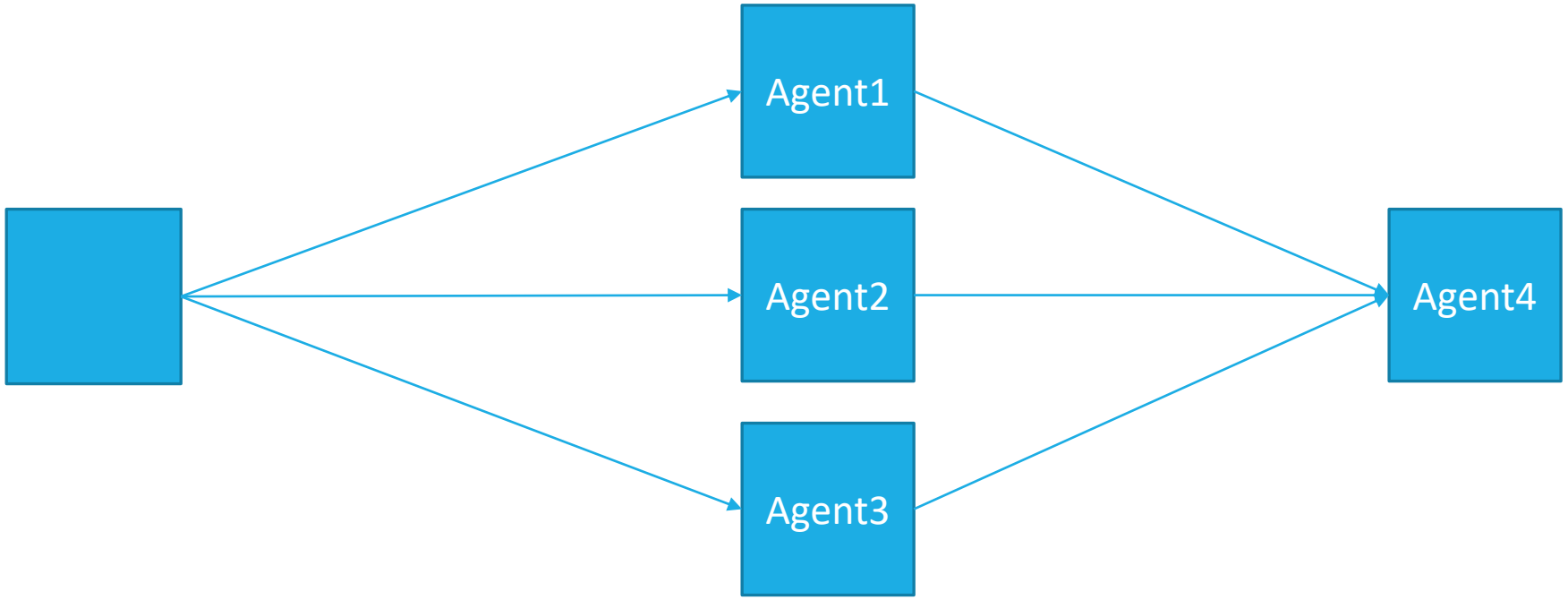
Agent patterns

Pool



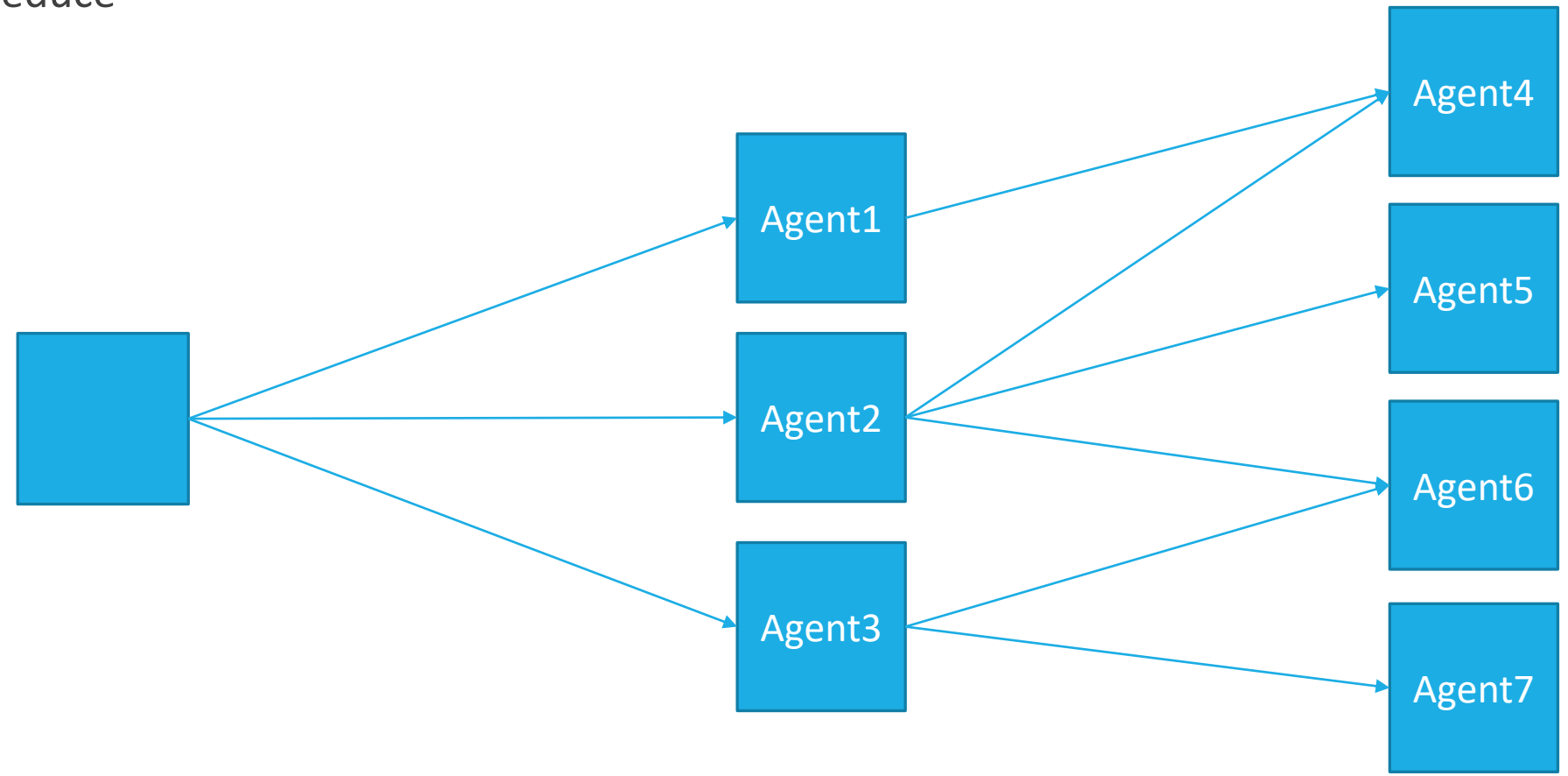
Agent patterns

Fork Join

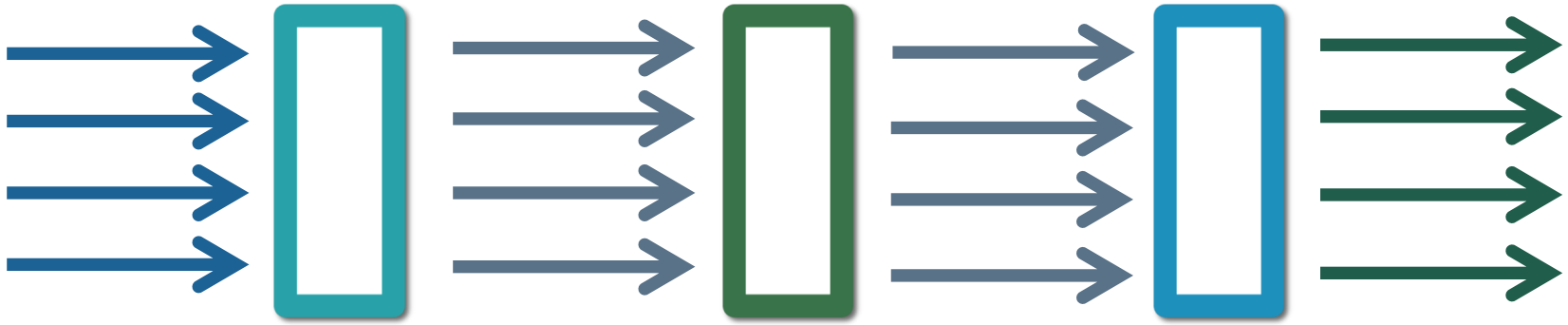


Agent patterns

Map Reduce



Pipeline Processing



- A pipeline is a set of data processing elements connected in series, so that the output of one element is the input of the next one. The elements of a pipeline are often executed in parallel or in time-sliced fashion; in that case, some amount of buffer storage is often inserted between elements

Agent Error Handling & Disposable

```
let errorAgent =
       Agent<int * System.Exception>.Start(fun inbox ->
         async { while true do
                    let! (agentId, err) = inbox.Receive()
                    printfn "an error '%s' occurred in agent %d" err.Message agentId })

let agent cancellationToken =
        new Agent<string>((fun inbox ->
                    async { while true do
                                let! msg = inbox.Receive()
                            failwith "fail!" }), cancellationToken.Token)
         agent.Error.Add(fun error -> errorAgent.Post (error))
          agent.Start()
          agent


// (agent :> IDisposable).Dispose()
```

Agent Replying to the sender

Message carries input and a callback

```
type Message = string * AsyncReplyChannel<string>
```

Reply using the callback object

```
let echo = Agent<Message>.Start(fun agent ->
 async { while true do
            let! name, rchan = agent.Receive()
            rchan.Reply("Hello " + name) })
```

Asynchronous communication

```
let! s = echo.PostAndAsyncReply(fun ch -> “F#", ch)
```

Agent State Machine

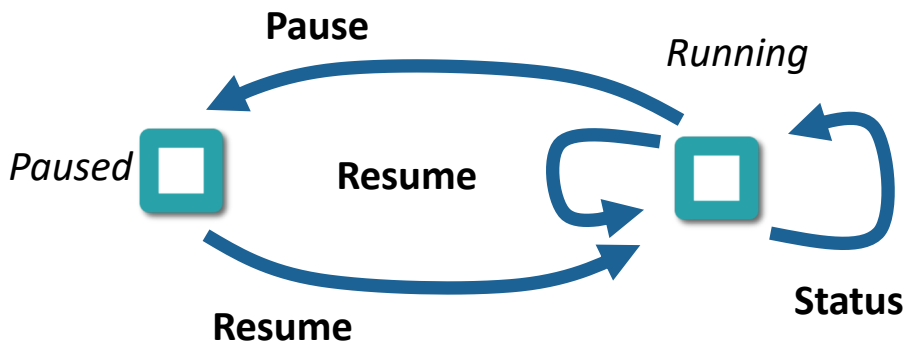
Multi-state agents use state machines

- Easy to implement as recursive functions
- Some states may leave messages in the queue

State transitions

- Accepting all messages, Asynchronously Receive and use pattern matching
- Waiting for a specific message, other messages stay in the queue

```
Agent.Start(fun agent ->
  let rec paused = agent.Scan (function
    | Resume -> Some (async {
        printfn "Resumed!"
        return! running })
    | _ -> None)
  and running = (* ... *) )
```



Agent Supervisors

```
let errorAgent =
      Agent<int * System.Exception>.Start(fun inbox ->
        async { while true do
                  let! (agentId, err) = inbox.Receive()
                  printfn "an error '%s' occurred in agent %d" err.Message agentId })

let agents10000 =
      [ for agentId in 0 .. 10000 ->
          let agent =
              new Agent<string>(fun inbox ->
                 async { while true do
                           let! msg = inbox.Receive()
                           if msg.Contains("agent 99") then
                               failwith "fail!" })
       agent.Error.Add(fun error -> errorAgent.Post (agentId,error))
          agent.Start()
          (agentId, agent) ]
```

Scaling agents on demand

```
let urlList = [ ("Microsoft.com", "http://www.microsoft.com/");
                ("MSDN", "http://msdn.microsoft.com/");
                ("Google", "http://www.google.com") ]

let processingAgent() = Agent<string * string>.Start(fun inbox ->
                        async { while true do
                                let! name,url = inbox.Receive()
                                let uri = new System.Uri(url)
                                let webClient = new WebClient()
                                let! html = webClient.AsyncDownloadString(uri)
                                printfn "Read %d characters for %s" html.Length name })

let scalingAgent : Agent<(string * string) list> = Agent.Start(fun inbox ->
                                 async { while true do
                                         let! msg = inbox.Receive()
                                         msg
                                         |> List.iter (fun x ->
                                                       let newAgent = processingAgent()
                                                       newAgent.Post x )})
```

Encapsulating agents

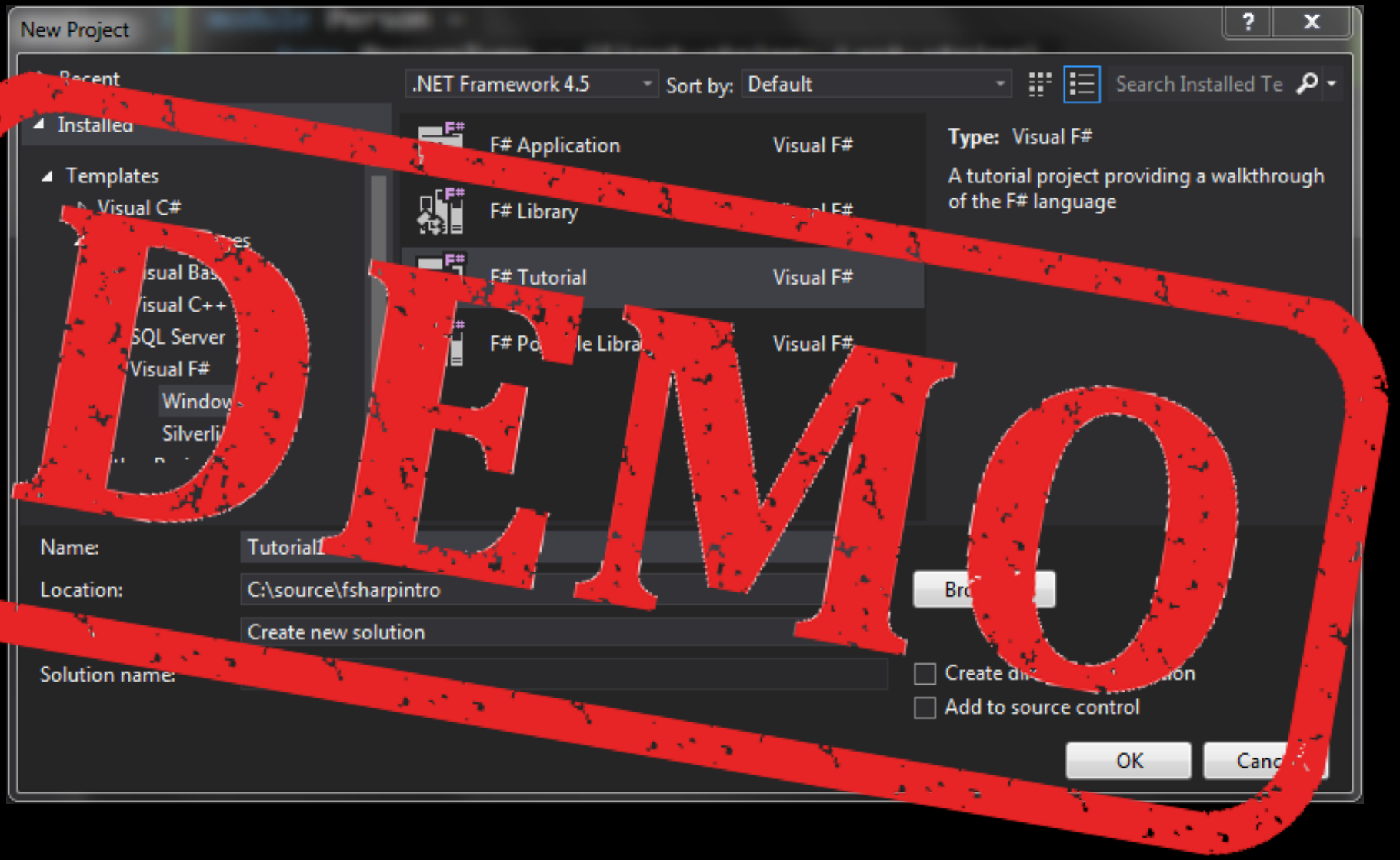
Create type and expose messages as members

```
type internal OnePlaceMessage<'T> =
  | Put of 'T
  | Get of AsyncReplyChannel<'T>

type OnePlaceAgent<'T>() =
  let agent = Agent.Start(fun agent -> (* ... *))
  member x.Put(value) = agent.Post(Put value)
  member x.AsyncGet() = agent.PostAndAsyncReply(Get)
```

- Ordinary methods for encapsulating `Post`
- Asynchronous methods when waiting for a reply

MailboxProcessor interoperability with C#

```
type internal OnePlaceMessage<'T> =
  | Put of 'T
  | Get of AsyncReplyChannel<'T>

type OnePlaceAgent<'T>() =
  let agent = Agent.Start(fun agent -> (* ... *))
  member x.Put(value) = agent.Post(Put value)
  member x.AsyncGet() = agent.PostAndAsyncReply(Get)
                        |> Async.StartAsTask
```


New Project
.NET Framework 4.5
Sort by:
Default
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Installed
Templates
Visual C#
Visual C++
SQL Server
Visual F#
Silverli
F# Application
Visual F#
F# Library
F# Tutorial
Visual F#
Visual F#
Type: Visual F#
A tutorial project providing a walkthrough of the F# language
Name:
Tutorial1
Location:
C:\source\fsharpintro
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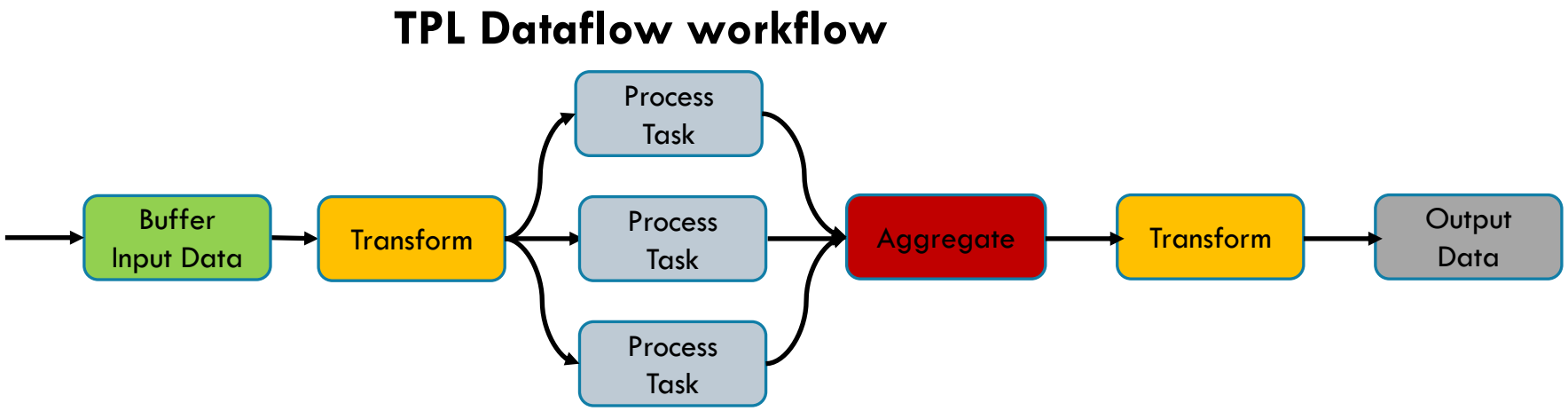
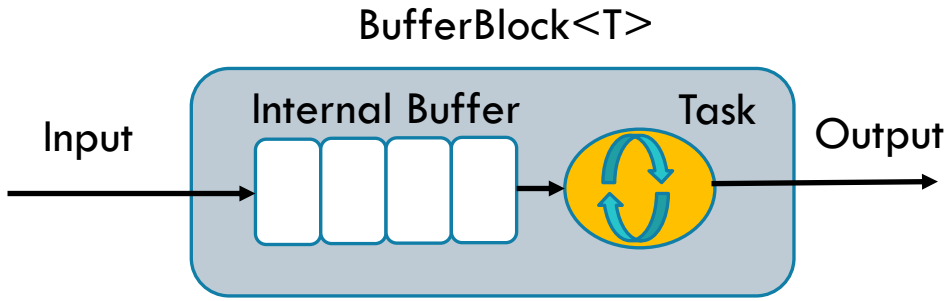
Solution name:
Add to source control
OK
DEMO

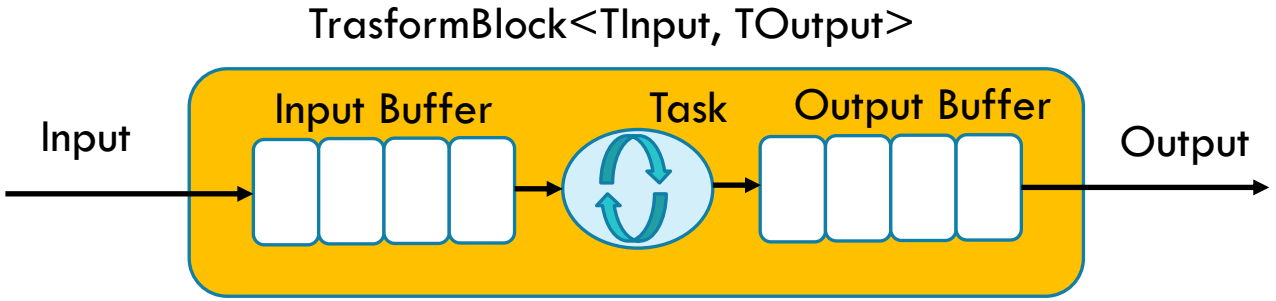
Agent in .NET and C#

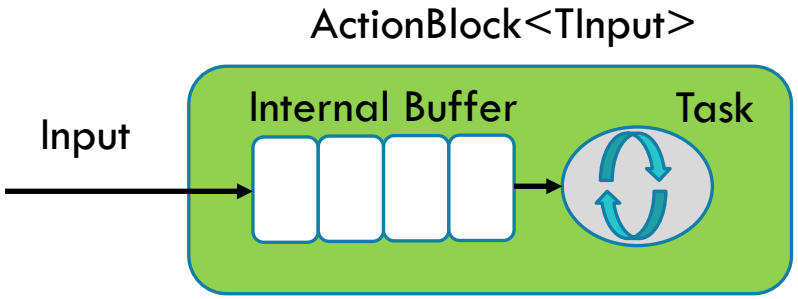
TPL DataFlow blocks –design to compose



Some Dataflow blocks







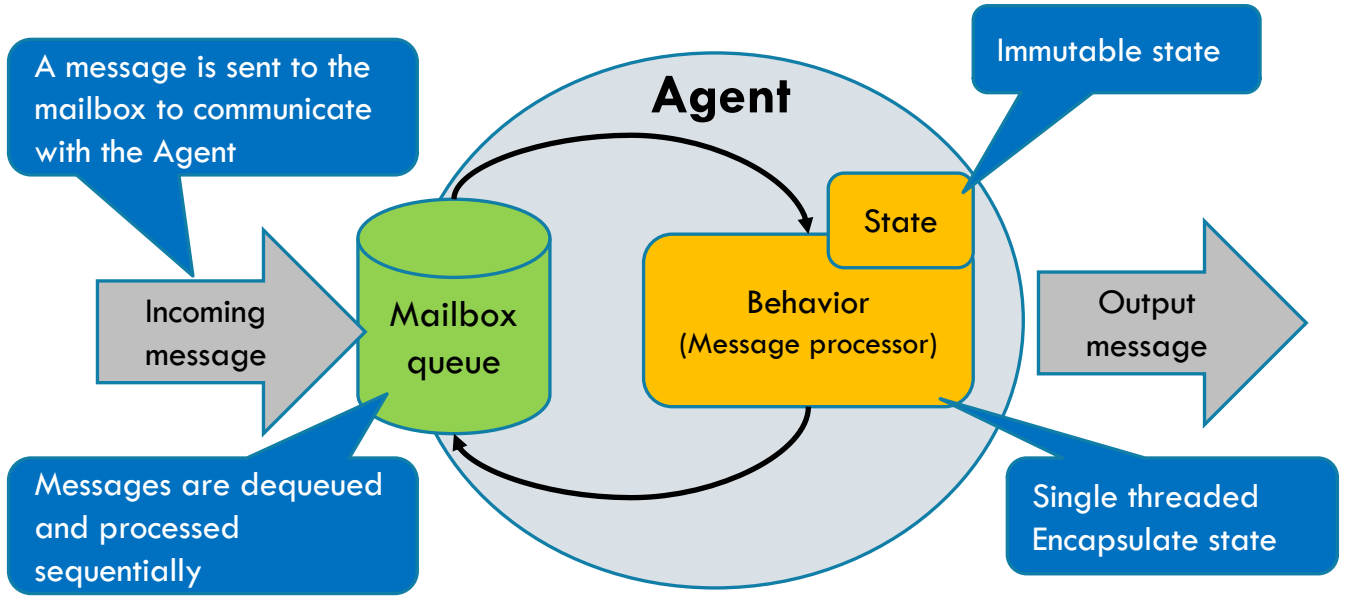
Simple producer-consumer

```
BufferBlock<int> buffer = new BufferBlock<int>();

async Task Producer(IEnumerable<int> values) {
       foreach (var value in values)
              buffer.Post(value);
       buffer.Complete();
}
async Task Consumer(Action<int> process)  {
       while (await buffer.OutputAvailableAsync())
             process(await buffer.ReceiveAsync());

}
async Task Run()  {
       IEnumerable<int> range = Enumerable.Range(0,100);
       await Task.WhenAll(Producer(range), Consumer(n =>
              Console.WriteLine($"value {n}")));
}
```

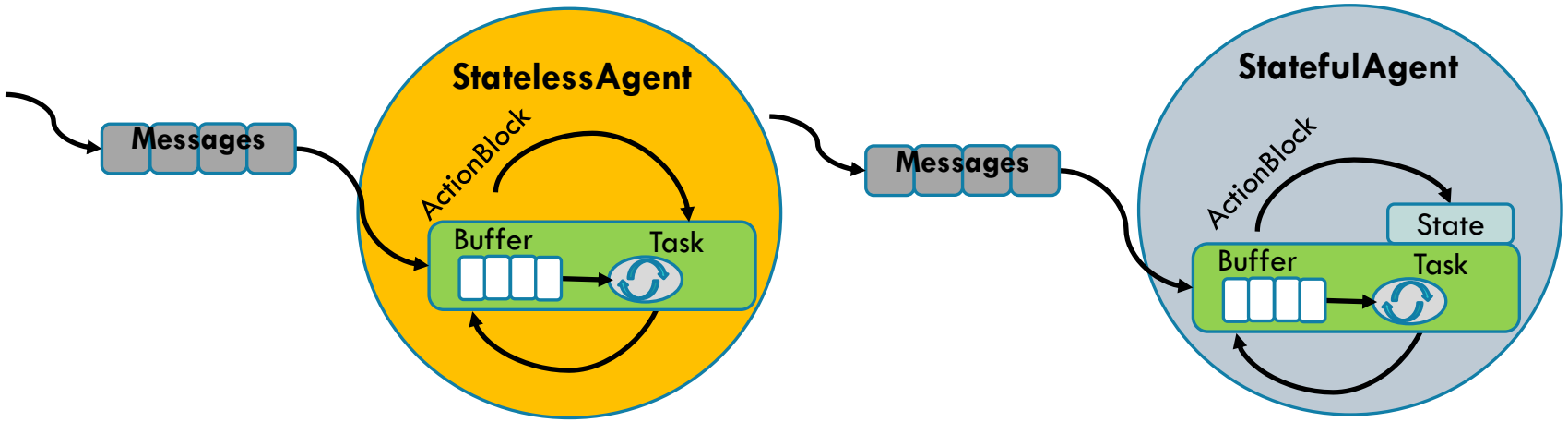
TPL DataFlow and Rx

```
inputBuffer.LinkTo(compressor, linkOptions);
compressor.LinkTo(encryptor, linkOptions);

encryptor.AsObservable()

          .Scan((new Dictionary<int, EncryptDetails>(), 0),
        (state, msg) => Observable.FromAsync(async() => {
         (Dictionary<int,EncryptDetails> details, int lastIndexProc) = state;
         details.Add(msg.Sequence, msg);

         return (details, lastIndexProc);
}) .SingleAsync())
.SubscribeOn(TaskPoolScheduler.Default).Subscribe();
```

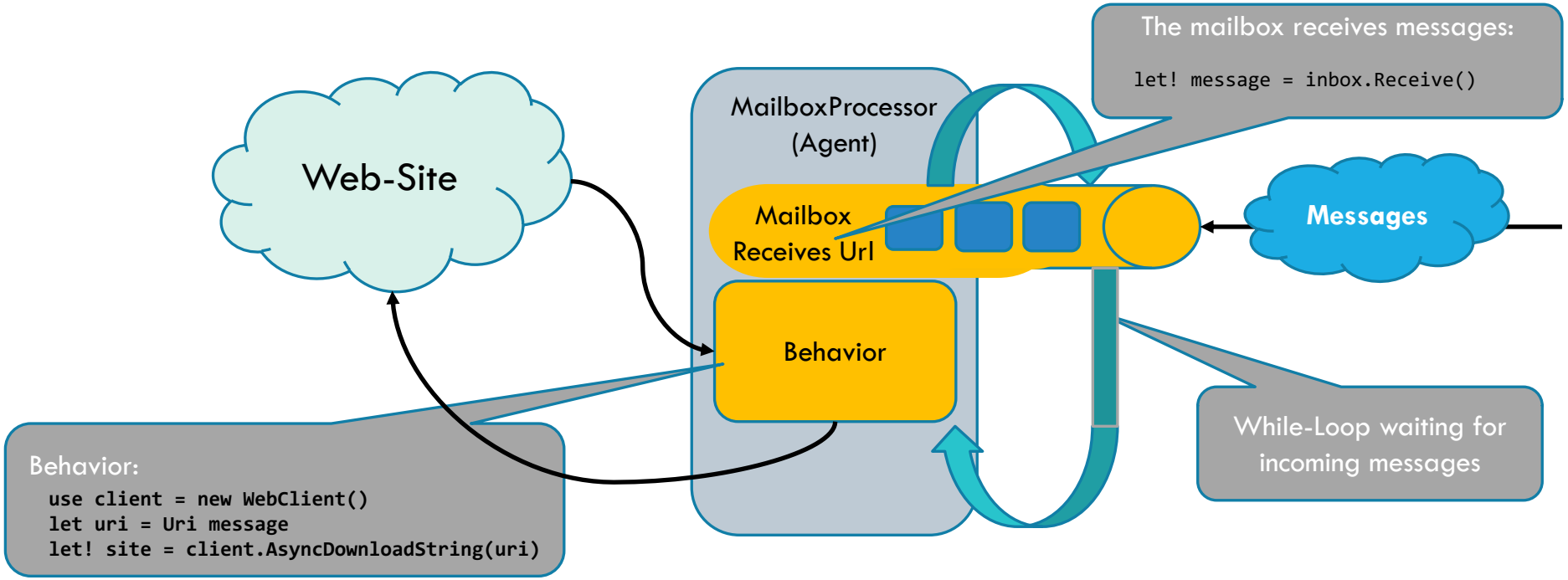
Agent anatomy



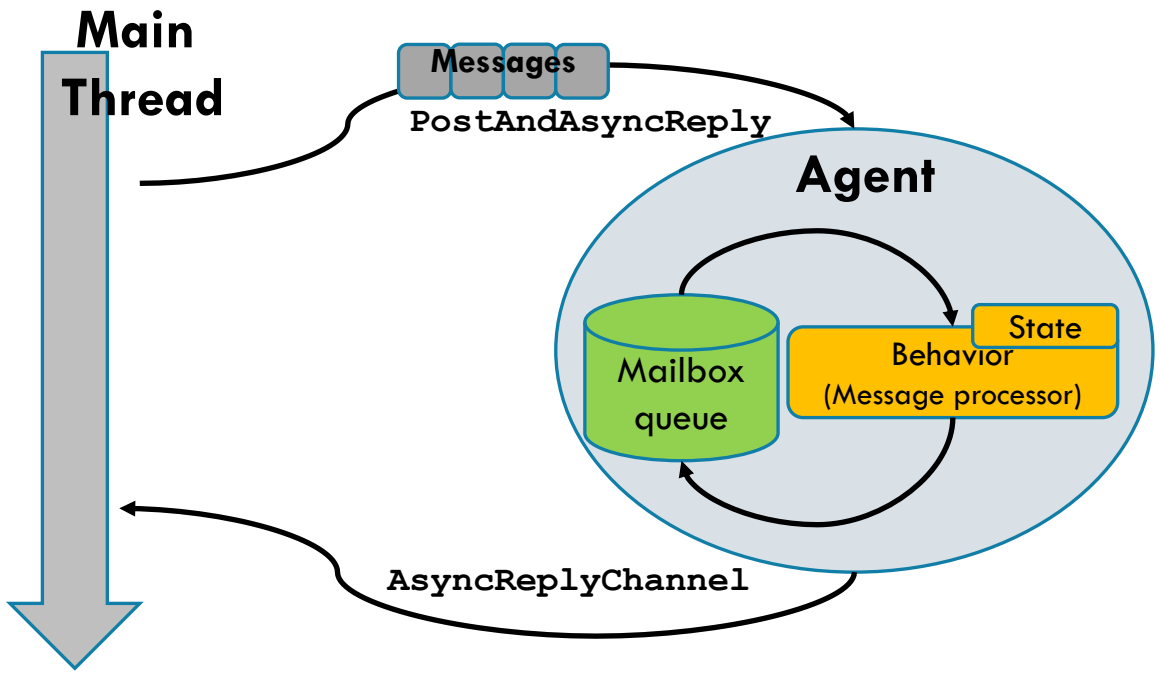
TPL DataFlow as Agent

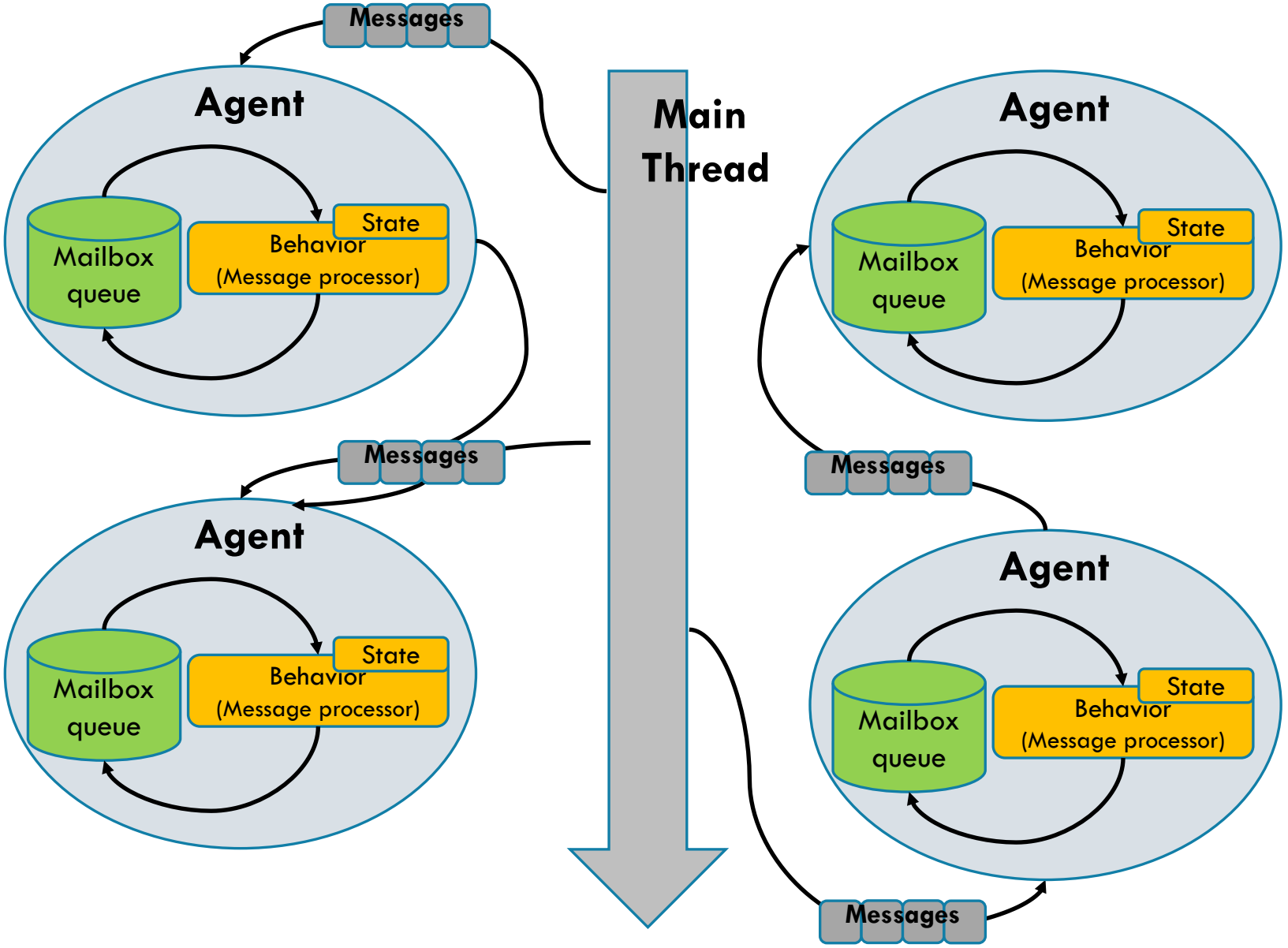


Agent anatomy



Agent two-way communication




Messages
Agent
Mailbox queue
State
Behavior (Message processor)
Main Thread
Agent
Mailbox queue
State
Behavior (Message processor)
Messages
Messages
Agent
Mailbox queue
State
Behavior (Message processor)
Agent
Mailbox queue
State
Behavior (Message processor)
Messages

Lab :
Implement a state full agent using TPL DataFlow

Agent in C#

```
class StatefulDataflowAgent<TState, TMessage> : IAgent<TMessage>
{
    private TState state;
    private readonly ActionBlock<TMessage> actionBlock;


    public StatefulDataflowAgent(
        TState initialState,
        Func<TState, TMessage, Task<TState>> action,
        CancellationTokenSource cts = null)
    {
        state = initialState;
        var options = new ExecutionDataflowBlockOptions
        {
            CancellationToken = cts != null ?
                cts.Token : CancellationToken.None
        };
        actionBlock = new ActionBlock<TMessage>(
            async msg => state = await action(state, msg), options);
    }

    public Task Send(TMessage message) => actionBlock.SendAsync(message);
    public void Post(TMessage message) => actionBlock.Post(message);
}
```

TPL DataFlow a statefull agent

```
class StatefulDataFlowAgent<TState, TMessage>
{
        private TState state;
        private readonly ActionBlock<TMessage> actionBlock;

        public StatefulDataFlowAgent(
                TState initialState,
                Func<TState, TMessage, Task<TState>> action,
                CancellationTokenSource cts = null)
         {
                        state = initialState;
                var options = new ExecutionDataFlowBlockOptions {
                CancellationToken = cts != null ?
                cts.Token : CancellationToken.None };

         actionBlock = new ActionBlock<TMessage>(async msg =>
                        state = await action(state, msg), options);
        }
        public Task Send(TMessage message) => actionBlock.SendAsync(message);
        public void Post(TMessage message) => actionBlock.Post(message);
}
```

Agent two-way communication in C#

```
public Task<TReply> Ask(TMessage message)
{
    var tcs = new TaskCompletionSource<TReply>();
    actionBlock.Post((message, Some(tcs)));
    return tcs.Task;
}

public StatefulReplyDataflowAgent(TState initialState,
Func<TState, TMessage, Task<TState>> projection,
Func<TState, TMessage, Task<(TState, TReply)>> ask,
CancellationTokenSource cts = null)
{
    state = initialState;
    actionBlock = new ActionBlock<(TMessage, Option<TaskCompletionSource<TReply>>)>(
        async message =>
        {
            (TMessage msg, Option<TaskCompletionSource<TReply>> replyOpt) = message;
            await replyOpt.Match(
                    none: async () => state = await projection(state, msg),
                    some: async reply => {
                        (TState newState, TReply replyresult) = await ask(state, msg);
                        state = newState;
                        reply.SetResult(replyresult);
                    });
```

TPL DataFlow caching web-sites downloaded

```
List<string> urls = new List<string> {
       ”http://www.google.com",
                    "http://www.microsoft.com",
                    "http://www.bing.com",
                    "http://www.google.com"
            };

var agentStateful = Agent.Start(ImmutableDictionary<string,string>.Empty,
   async (ImmutableDictionary<string,string> state, string url) => {
          if (!state.TryGetValue(url, out string content))
       using (var webClient = new WebClient()){
         content = await webClient.DownloadStringTaskAsync(url);
         await File.WriteAllTextAsync(createFileNameFromUrl(url), content);
         return state.Add(url, content);
      }
   return state;
   });

urls.ForEach(url => agentStateful.Post(url));
```

Agent fold-over state and messages (Aggregate)

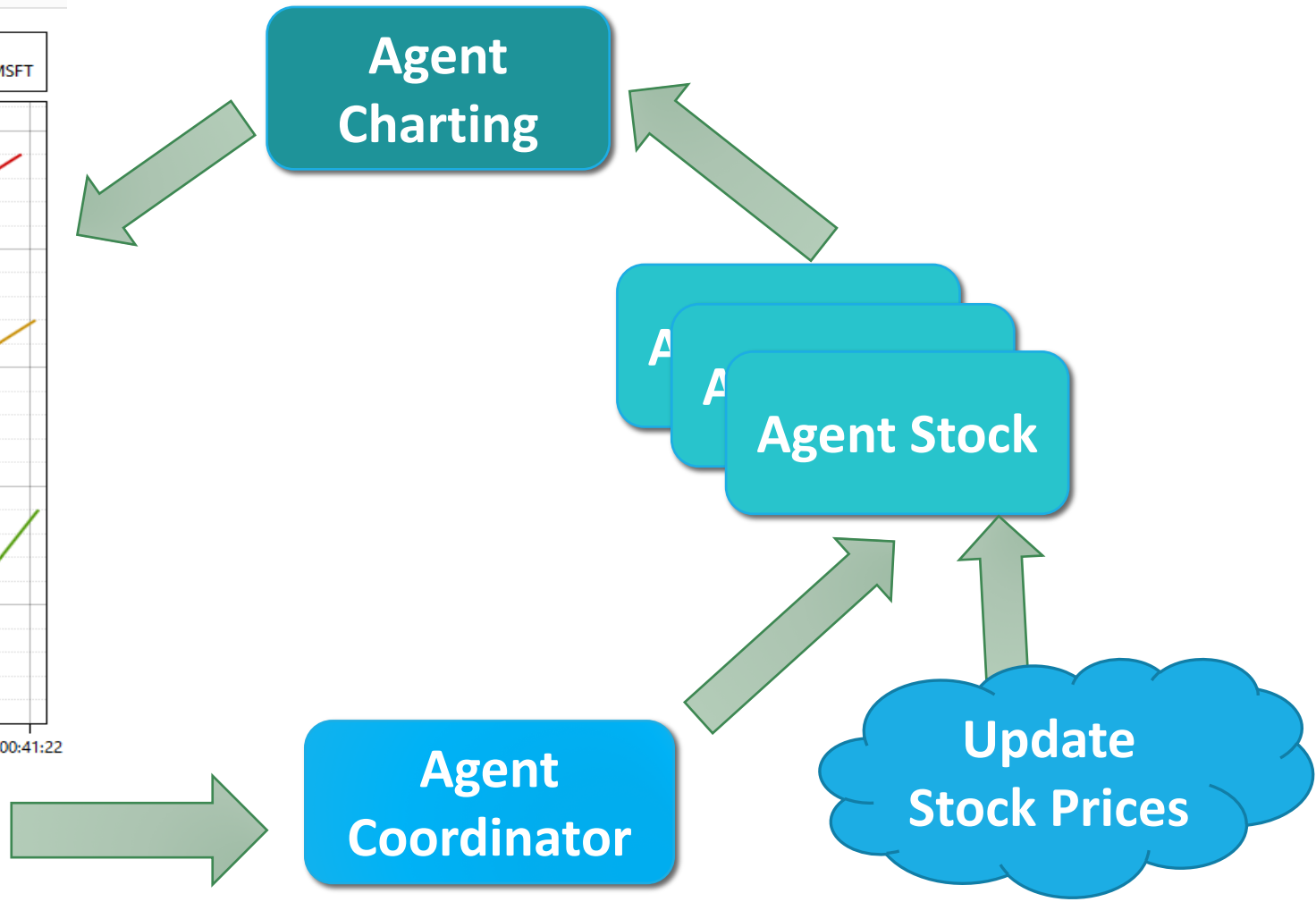
```
Agent(ImmutableDictionary<string,string>.Empty,
        async (state, url) => {
if (!state.TryGetValue(url, out string content))
  using (var webClient = new WebClient())
  {
        content = await webClient.DownloadStringTaskAsync(url);
        await File.WriteAllTextAsync(createFileNamFromUrl(url),     content);
        return state.Add(url, content);
  }
  return state;
});
```

Agent fold-over state and messages (Aggregate)

```
urls.Aggregate(ImmutableDictionary<string,string>.Empty,
        async (state, url) => {
if (!state.TryGetValue(url, out string content))
  using (var webClient = new WebClient())
  {
        content = await webClient.DownloadStringTaskAsync(url);
        await File.WriteAllTextAsync(createFileNamFromUrl(url),     content);
        return state.Add(url, content);
  }
  return state;
});
```

Lab :
Agent Stock Ticker

Agent Stock Ticker

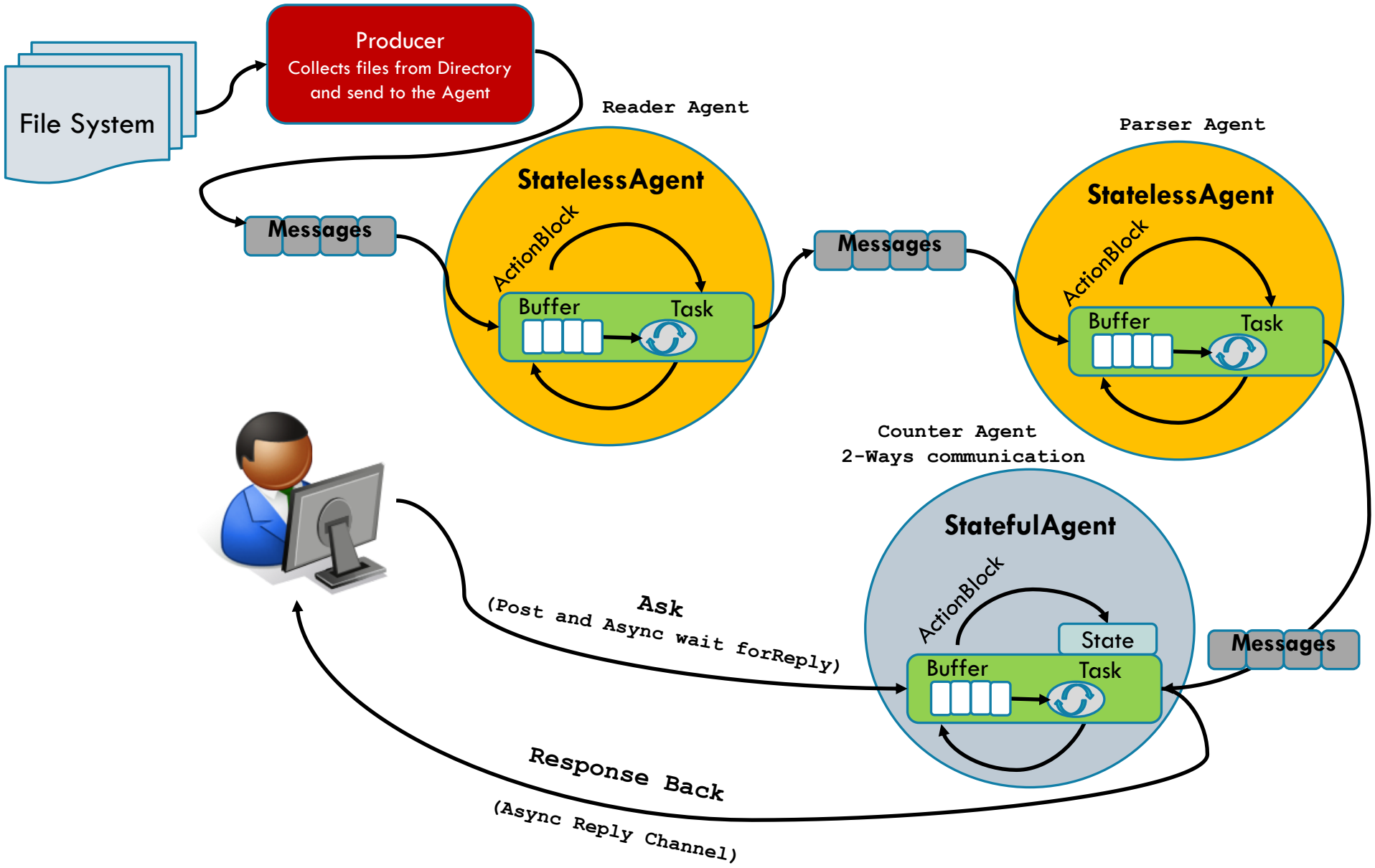


Agent Stock Ticker

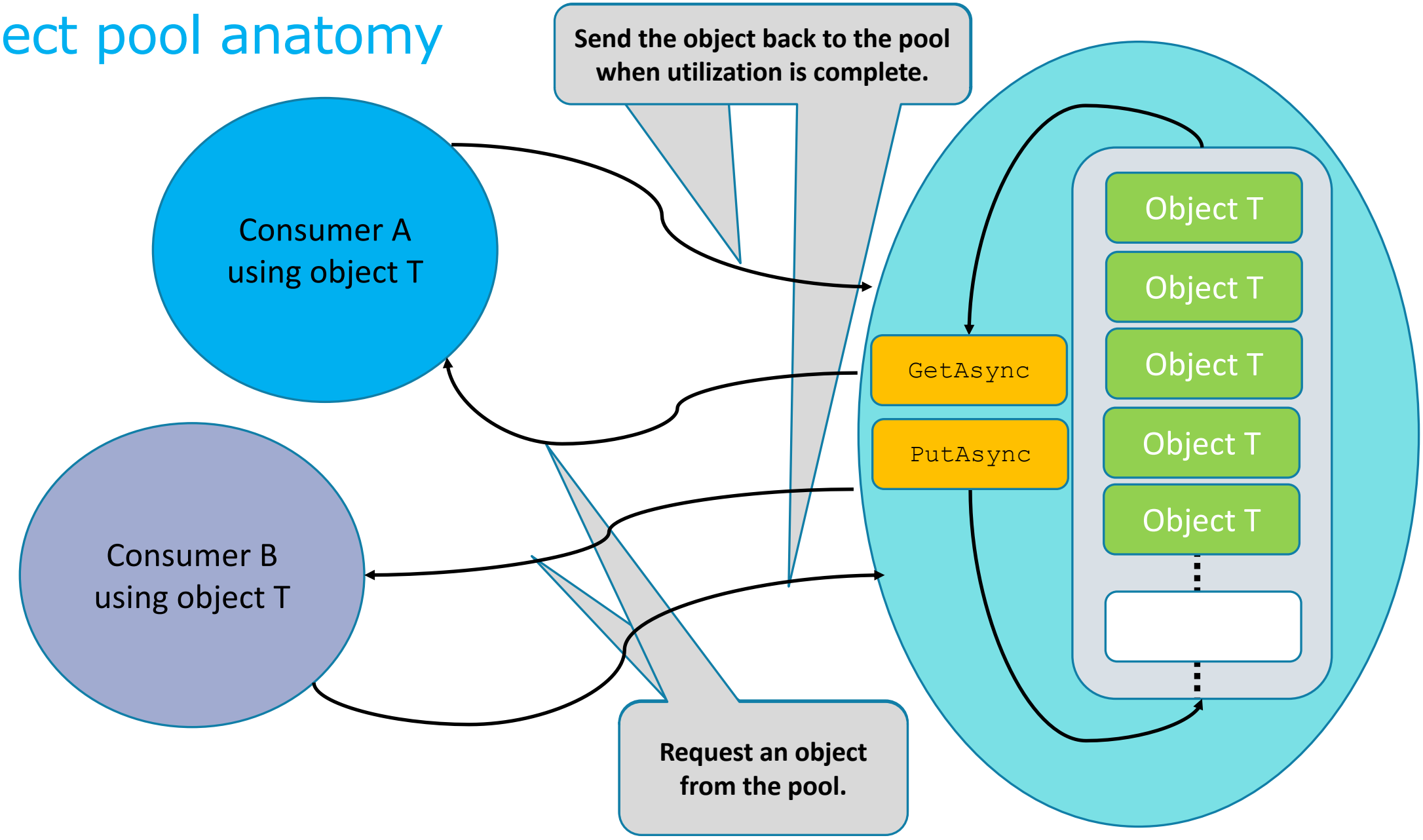
Tasks:

1. Create Agent hierarchy Children-Parent (sub-pub)
   - Create Agent Stock (one per stock symbol)
   - Create Agent Coordinator for subscribe/unsubscribe Agent Stocks
2. Connect Agents using messages

Agent for producer and consumer pattern


File System
Producer
Collects files from Directory and send to the Agent
Reader Agent
StatelessAgent
ActionBlock
Buffer
Task
Messages
Parser Agent
StatelessAgent
ActionBlock
Buffer
Task
Messages
Counter Agent
2-Ways communication
StatefulAgent
ActionBlock
State
Buffer
Task
Messages
Ask
(Post and Async wait forReply)
Response Back
(Async Reply Channel)

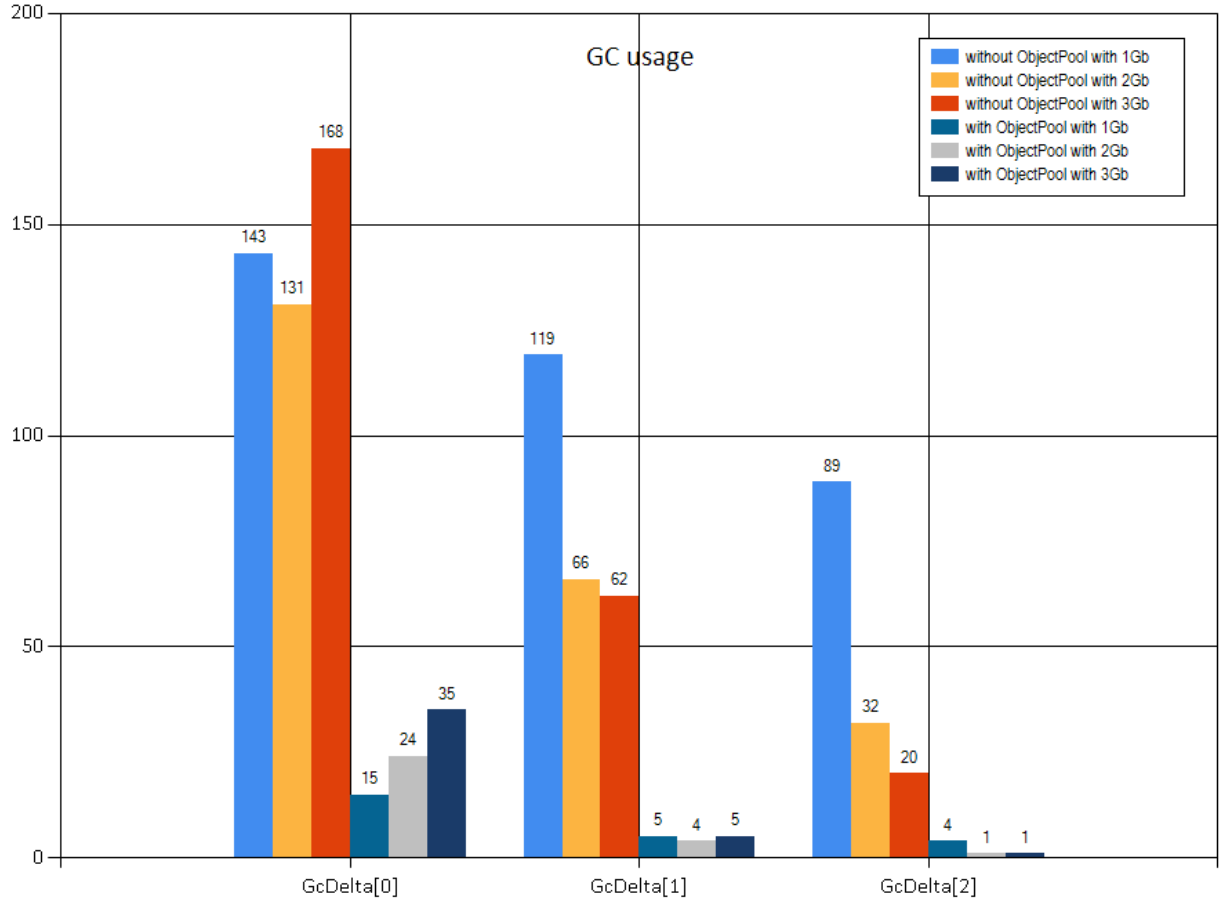
Object pool anatomy



Async-PoolObject

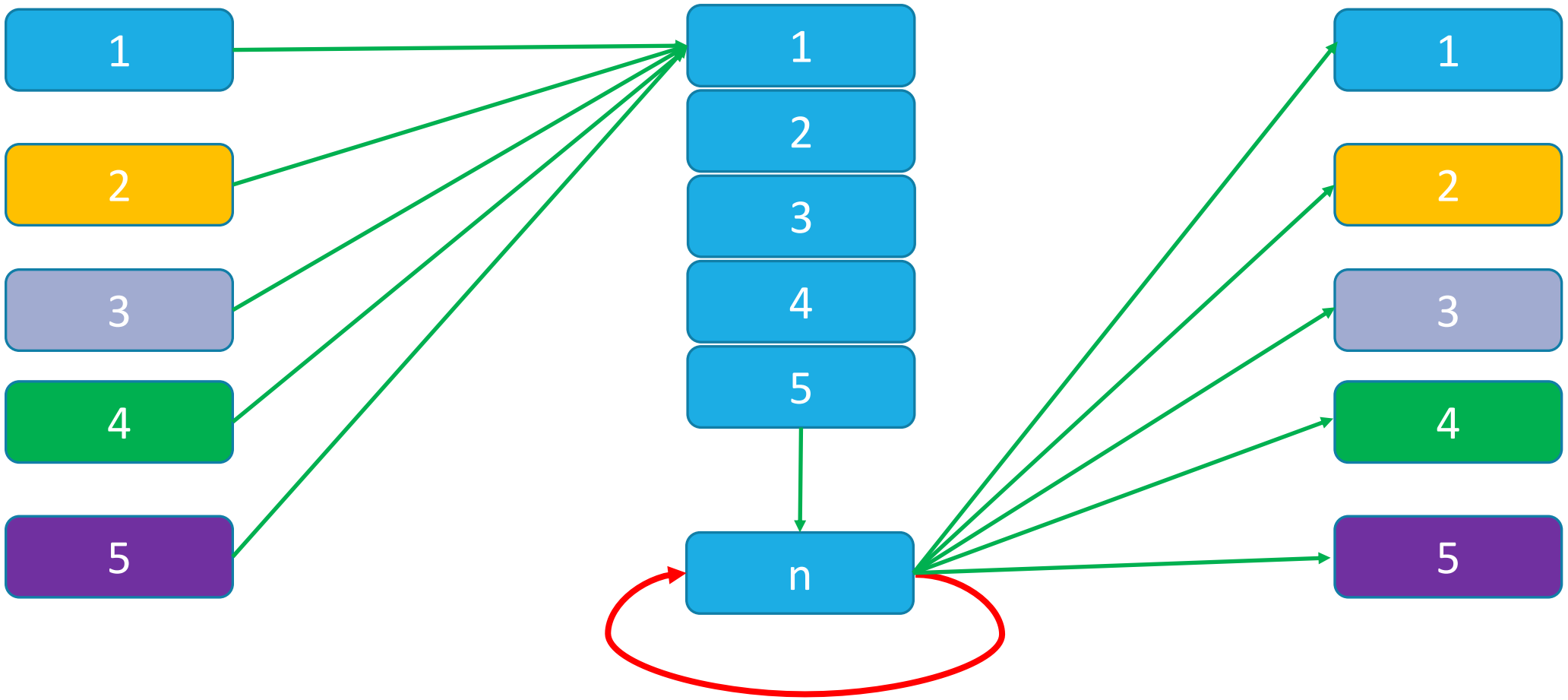
```
public class ObjectPoolAsync<T>
{
    private readonly BufferBlock<T> buffer;
    private readonly Func<T> factory;
    private readonly int msecTimeout;
    private int currentSize;

    public ObjectPoolAsync(int initialCount, Func<T> factory, CancellationToken cts, int msecTimeout = 0)
    {
        this.msecTimeout = msecTimeout;
        buffer = new BufferBlock<T>(  // #A
            new DataflowBlockOptions { CancellationToken = cts });
        this.factory = () => {
            Interlocked.Increment(ref currentSize);
            return factory();
        };
        for (int i = 0; i < initialCount; i++)
            buffer.Post(this.factory());  // #B
    }
    public int Size => currentSize;

    public Task<bool> PushAsync(T item) =>  …
    public Task<T> GetAsync(int timeout = 0)   …
```

Async-PoolObject benefit

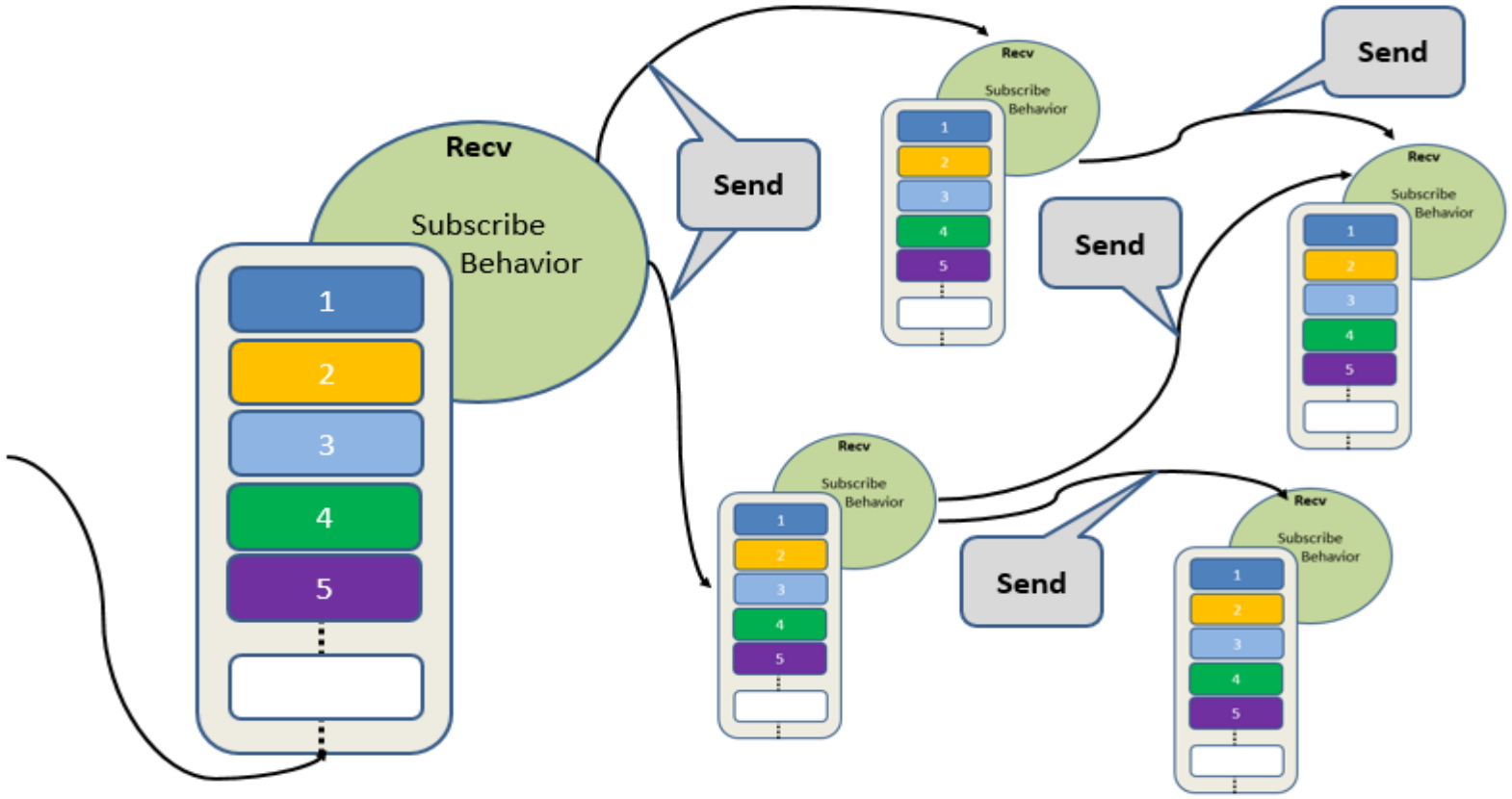


Channel

Channel



Channel


Recv
Subscribe
Behavior
1
2
3
4
5
Send
Send
Send
Send
Recv
Subscribe
Behavior
Recv
Subscribe
Behavior
Recv
Subscribe
Behavior
Recv
Subscribe
Behavior

```
type [<Sealed>] Channel<'T>() =
    let channelAgent =
        MailboxProcessor<ChannelMsg<'T>>.Start(fun inbox ->
            let readers = Queue()
            let writers = Queue()
            let rec loop () = async {
                let! msg = inbox.Receive()

                match msg with
                | Read ok when writers.Count = 0 ->
                    readers.Enqueue ok
                    return! loop()
                | Read ok -> let value, cont = writers.Dequeue()
                             Pool.Spawn cont
                             ok value
                             return! loop()
                | Write (x,ok) when readers.Count = 0 ->
                          writers.Enqueue(x, ok)
                          return! loop()
                | Write (x,ok) ->  let cont = readers.Dequeue()
                                   Pool.Spawn ok
                                   cont x
                                   return! loop() }
            loop() )

    member this.Read(read) = channelAgent.Post (Read read)
    member this.Write(v, ok) = channelAgent.Post (Write (v,ok))

    member inline this.Read() = Async.FromContinuations(fun (ok, _, _) -> this.Read ok)
    member inline this.Write x = Async.FromContinuations(fun (ok, _, _) -> this.Write(x,ok))
```

Lab :
Channel in action (broadcasting)

The tools we use have a profound (and devious!) influence on our thinking habits, and, therefore, on our thinking abilities.

-- Edsger Dijkstra