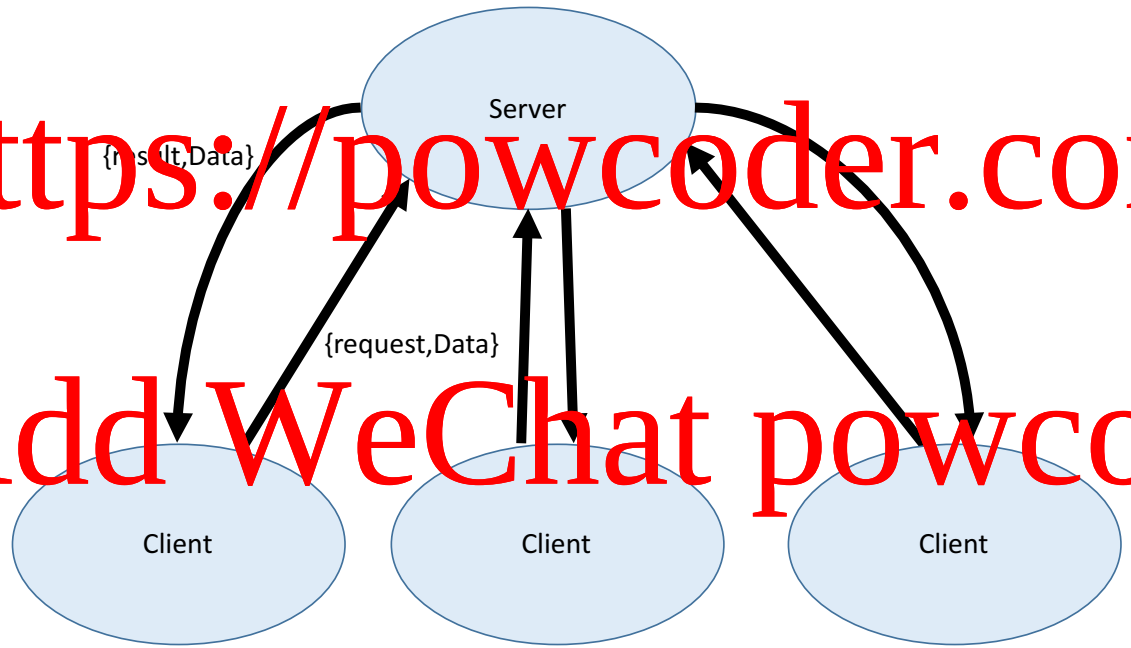
Communication Patterns

CS61

Client-Server Architecture

- Common asynchronous communication pattern
- For example: a web server handles requests for web pages from clients (web browsers)



Example: Factorial Server

```
1  -module(mserver).
2  -export([start/0,compute_factorial/2]).
3  -import(fact,[fact/1]).
4
5  loop(Count) ->
6      receive
7          {get_count, From, Ref} ->
8                      From ! {result, Ref, Count},
9                      loop(Count);
10
11         {factorial, From, Ref, N} ->
12                     Result = fact(N),
13                     From ! {result, Ref, Result},
14                     loop(Count+1);
15
16         stop -> true
17     end.
18
19 % starting server with initial state 0
20 start() -> spawn(fun() -> loop(0) end).
```


Note how the server state is a parameter of loop

Example: Factorial Server

Client

```
1 compute_factorial(Pid, N) ->
2     Ref = make_ref(),
3     Pid ! {factorial, self(), Ref, N},
4     receive
5         {result, Ref, Result} ->
6             Result
7     end.
```

Test

```
1 > c(mserver).
2 {ok,mserver}
3 > P=mserver:start().
4 <0.40.0>
5 > mserver:compute_factorial(P,10).
6 3628800
```

Example: Factorial Server

What if the server crashes or stops?

```
1 > P ! stop
2 > mserver:compute_factorial(P,10).
3 ...no response...
```


- Why do we get no response?
- Can you modify the code so that we receive a `timeout`?

Registered Processes – Recap

- As seen in class, Erlang has a method for publishing a process identifier
  - Any other process can communicate with it
- BIF `register`


```
1 % starting server with initial state 0
2 start() ->
3     Pid = spawn(fun() -> loop(0) end),
4     register(server,Pid).
```


- Unregister with `unregister(name)`
- Registration lookup `whereis(name)`

Registered Processes – Recap

The atom server can be used instead of a concrete process ID.

```
1 > mserver2:start().
2 true
3 > mserver2:compute_factorial(server,10).
4 3628800
5 > server ! stop.
6 stop
7 > mserver2:compute_factorial(server,10).
8 ** exception error: bad argument
9      in function  mserver2:compute_factorial/2 (mserver2.erl, line
10 > mserver2:start().
11 true
12 > mserver2:compute_factorial(server,10).
13 3628800
```

Distributed Environments

- Message passing abstractions extend easily for distributed environments
- Erlang nodes
  - An instance of an Erlang runtime system
  - Nodes can easily communicate with each other
    - Creating a node


```
erl -name 'nodeS@127.0.0.1' -setcookie lecture
```


    - The cookie provides security (not everyone can connect)
    - The name reflects the node's IP address

Distributed Environments

- Creating two nodes (for simplicity on the same machine)

```
1 erl -name 'nodeS@127.0.0.1' -setcookie lecture
2 erl -name 'nodeC@127.0.0.1' -setcookie lecture
```


- Connecting nodes
  - From `nodeC@127.0.0.1`

```
1 (nodeC@127.0.0.1)> net_adm:ping('nodeS@127.0.0.1').
2 pong
3 (nodeC@127.0.0.1)> nodes().
4 ['nodeS@127.0.0.1']
```

Distributed Factorial Server – Running Your Code

Send the compiled version of your code to the connected nodes

```
(nodeC@127.0.0.1)> nl(fact).
abcast
(nodeC@127.0.0.1)> nl(mserver2).
abcast
```

The server gets started on the nodeS node

```
(nodeS@127.0.0.1)> mserver2:start().
true
```

The client communicates with the server

```
(nodeC@127.0.0.1)> mserver2:compute_factorial({server,
                                'nodeS@127.0.0.1'}, 10).
3628800
```

- Use of `{registered_name, node@IP}` instead of the pid or only the registered name
- Code has not been changed for running in a distributed setting!

A Generic Server

- The code for a generic server takes care of the communication, faults, and upgrades
- Programmers then only focus on writing the engine (i.e. what the server does)
- No communication primitives are required in the engine

A Generic Server

The code must expose the following features:

- Correct
  - It implements a proper server/client request/reply interaction
- Parametrized
  - It is parametric on the engine
- Robust
  - It does not crash if the engine goes wrong
- Upgradable
  - It allows to upgrade the engine of the server without shutting it down

A Generic Server

```
1  loop(State, F) ->
2      receive
3          {update, From, Ref, NewF} ->
4              From ! {ok, Ref},
5              loop(State, NewF) ;
6
7          {request, From, Ref, Data} ->
8              {R, NS} = F(State, Data),
9              From ! {result, Ref, R},
10             loop(NS, F);
11
12         stop -> true
13
14     end.
```

How can the server go wrong when evaluating `F(State,Data)`?

Exceptions – The evaluation of expressions can fail

- Arithmetic error

```
1> 1/0.
2 ** exception error: bad argument in an arithmetic expression
3     in operator  '/'/2
4        called as 1 / 0
```

- Bad pattern matching

```
1 [] = [1].
2 ** exception error: no match of right hand side value [1]
```

- Undefined functions

```
1 net_adm:ping(1,2).
2 ** exception error: undefined function net_adm:ping/2
```

Exceptions

```
> catch(1/0).
{'EXIT',{badarith,[{erlang,'/',[1,0]},
                   {erl_eval,do_apply,5},
                   {erl_eval,expr,5},
                   {shell,exprs,7},
                   {shell,eval_exprs,7},
                   {shell,eval_loop,3}]}}
> catch([] = [1]).
{'EXIT',{{badmatch,[]},[{erl_eval,expr,3}]}}
> catch(net_adm:ping(1,2)).
{'EXIT',{undef,[{net_adm,ping,[1,2]},
                {erl_eval,do_apply,5},
                {erl_eval,expr,5},
                {shell,exprs,7},
                {shell,eval_exprs,7},
                {shell,eval_loop,3}]}}
>
```

Exceptions

```
1  loop(State, F) ->
2      receive
3          {update, From, Ref, NewF} ->
4              From !{ok, Ref},
5              loop(State, NewF);
6
7          {request, From, Ref, Data} ->
8              case catch(F(State, Data)) of
9                  {'EXIT', Reason} ->
10                     From!{exit, Ref, Reason},
11                     loop(State, F);
12                 {R, NewState} ->
13                     From!{result, Ref, R},
14                     loop(NewState, F)
15             end
16
17         stop -> true
18 end.
```


- It propagates the exception from the server to the client

Exceptions

```
1  loop(State, F) ->
2      receive
3          {update, From, Ref, NewF} ->
4              From !{ok, Ref},
5              loop(State, NewF);
6
7          {request, From, Ref, Data} ->
8              case catch(F(State, Data)) of
9  ,,             {'EXIT', Reason} ->
10 ,,                 From!{exit, Ref, Reason},
11 ,,                 loop(State, F);
12                 {R, NewState} ->
13                     From!{result, Ref, R},
14                     loop(NewState, F)
15             end
16
17         stop -> true
18 end.
```


- It propagates the exception from the server to the client

Exceptions

```
1  loop(State, F) ->
2      receive
3          {update, From, Ref, NewF} ->
4              From !{ok, Ref},
5              loop(State, NewF);
6
7          {request, From, Ref, Data} ->
8              case catch(F(State, Data)) of
9                  {'EXIT', Reason} ->
10                 From!{exit, Ref, Reason},
11                 loop(State, F);
12             {R, NewState} ->
13                 From!{result, Ref, R},
14                 loop(NewState, F)
15             end;
16
17         stop -> true
18 end.
```


- It propagates the exception from the server to the client

Starting the Generic Server


```
1 start(Name, State, F) ->
2     Pid = spawn(fun() -> loop(State, F) end),
3     register(Name, Pid),
4     Pid.
```

Generic Client

- Requests

```
1 request(Pid, Data) ->
2     Ref = make_ref(),
3     Pid!{request, self(), Ref, Data},
4     receive
5         {result, Ref, Result} ->
6             Result;
7         {exit, Ref, Reason} ->
8             exit(Reason)
9     end.
```

Generic Client

- Upgrading the server's engine

```
1 update(Pid, Fun) ->
2     Ref = make_ref(),
3     Pid!{update, self(), Ref, Fun},
4     receive
5       {ok, Ref} ->
6           ok
7     end.
```

Factorial Server Revisited

```
1  -module(factServer).
2  -export([start/0,compute_factorial/1]).
3  -import(fact, [fac/1]).
4
5  engine(Count, {factorial,N}) ->
6      Result = math_examples:factorial(N),
7      {Result, Count+1} ;
8
9  engine(Count, get_count) ->
10     {Count, Count}.
11
12 start() ->
13     genserver:start(server, 0, fun engine/2).
14
15 compute_factorial(N) ->
16     genserver:request(server, {factorial, N}).
```

- Observe that there are no message passing primitives!

Factorial Server Revisited


```
4> factServer:start().
<0.69.0>
5> factServer:compute_factorial(23).
25852016738884976640000
```

Client-Server Architecture

A Generic Server

Concurrency Patterns

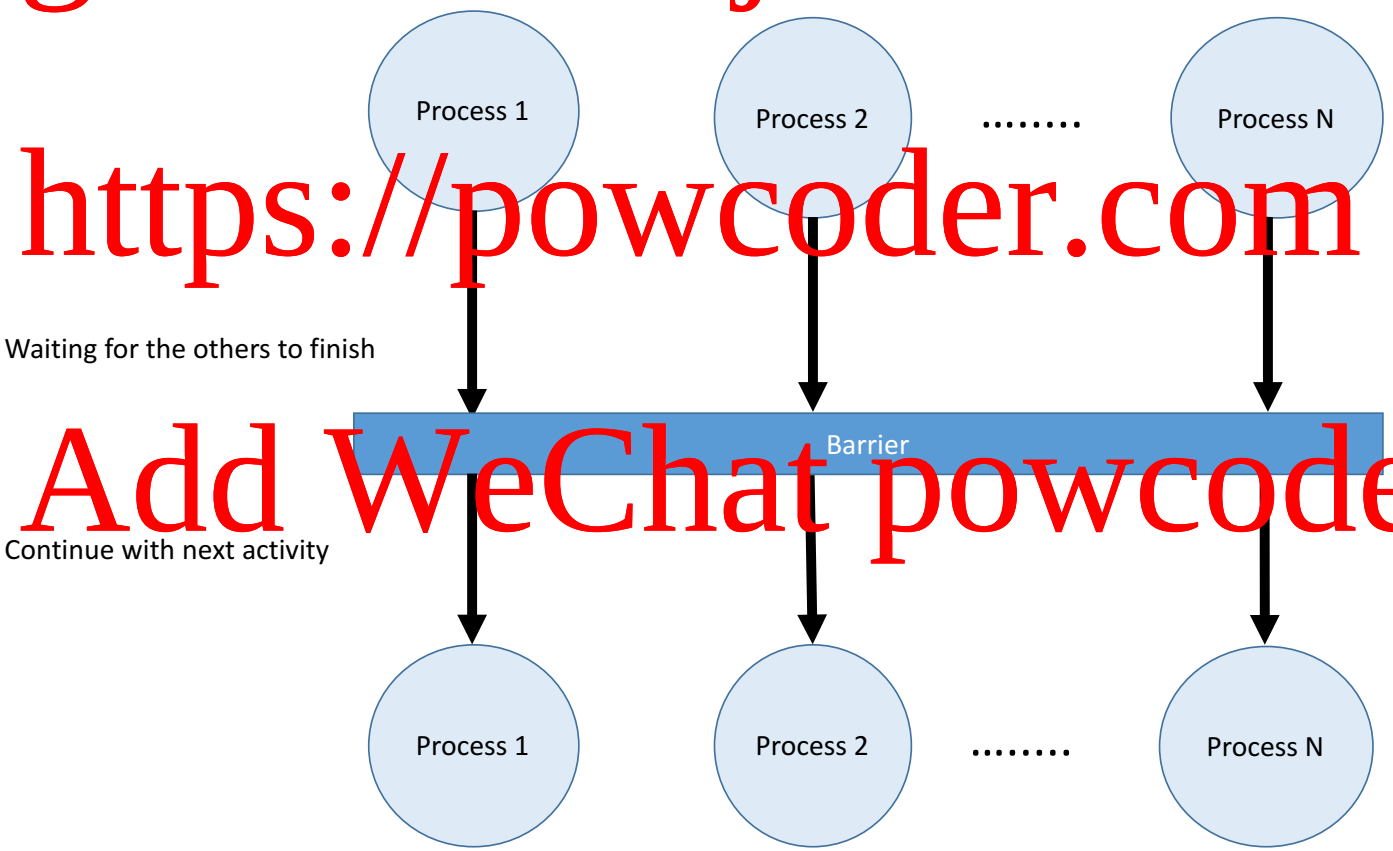
Concurrency Examples and Patterns Revisited

Revisiting the following using message passing:

- A semaphore (already seen last class)
- Barrier synchronisation
- Resource allocation
- Readers and writers

Barrier Synchronization Revisited

- N processes must wait for the slowest before continuing with the next activity
- Widely used in parallel programming



Barrier Synchronization Revisited

```
1  start(N) ->
2      Pid = spawn(fun() -> coordinator(N,N,[]) end),
3      register(coordinator, Pid).
4
5  coordinator(N,0,Ps) ->
6      [From ! {ack, Ref} || {From, Ref} <- Ps],
7      coordinator(N,N,[]);
8
9  coordinator(N,M,Ps) ->
10     receive
11         {reach, From, Ref} ->
12             coordinator(N,M-1,[{From,Ref}|Ps])
13     end.
```

Barrier Synchronization Revisited

Using the barrier

```
1 reach_wait(Server) ->
2     Ref = make_ref(),
3     Server ! {reach, self(), Ref},
4     receive
5         {ack, Ref} -> true
6     end.
```

Resource Allocation

- A controller controls access to copies of some resources (of the same kind)
- Clients requiring multiple resources should not ask for resources one at a time

- Clients make requests to take or return any number of the resources
  - A request should only succeed if there are sufficiently many resources available
  - Otherwise the request must block

Resource Allocation


```
1  > c(ralloc).
2  {ok,ralloc}
3  > ralloc:start([1,1,1,1]).
4  true
5  > ralloc:request(3).
6  [1,1,1]
7  > ralloc:release([1]).
8  ok
9  > ralloc:request(2).
10 [1,1]
11 > ralloc:request(1).
```

In the last line, the process blocks

Resource Allocation

```
1  loop(Resources) ->
2      Available = length(Resources),
3      receive
4          {req, From, Ref, Number} when Number =< Available ->
5              From ! {res, Ref, lists:sublist(Resources, Number)},
6              loop(lists:sublist(Resources, Number+1, Available)) ;
7
8          {ret, List} -> loop(lists:append(Resources, List))
9      end.
10
11 % continues...
```


- Function `lists:sublist` returns a slice of a list; Examples


```
1 > lists:sublist([1,2,3,4], 2).
2 [1,2]
3 > lists:sublist([1,2,3,4], 2, 2).
4 [2,3]
5 > lists:sublist([1,2,3,4], 2, 5).
6 [2,3,4]
7 > lists:sublist([1,2,3,4], 5, 2).
8 []
```

Resource Allocation

```
1  start(Init) ->
2      Pid = spawn(fun() -> loop(Init) end),
3      register(rserver, Pid).
4
5
6  request(N) ->
7      Ref = make_ref(),
8      rserver ! {req, self(), Ref, N},
9      receive
10         {res, Ref, List} -> List
11     end.
12
13 release(List) ->
14     rserver ! {ret, List},
15     ok
```

Readers and Writers Revisited

- Two kinds of processes share access to a "database"
- Readers examine the contents
  - Multiple readers allowed concurrently
- Writers examine and modify data
  - A writer must have mutex
- Readers and writers in a few lines

Readers and Writers Revisited

```
1  loop(Rs, Ws) ->
2      receive
3          {start_read, From, Ref} when Ws =:= 0 ->
4              From ! {ok_to_read, Ref},
5              loop(Rs+1,Ws) ;
6
7          {start_write, From, Ref} when Ws =:= 0 and Rs =:= 0 ->
8              From ! {ok_to_write, Ref},
9              loop(Rs, Ws+1) ;
10
11         end_read   -> loop(Rs-1, Ws) ;
12
13         end_write  -> loop(Rs, Ws-1)
14     end.
```

Is it a fair solution?

Readers and Writers Revisited

```
1  loop(Rs, Ws) ->
2      receive
3          {start_read, From, Ref} when Ws =:= 0 ->
4              From ! {ok_to_read, Ref},
5              loop(Rs+1,Ws) ;
6
7          {start_write, From, Ref} when Ws =:= 0 and Rs =:= 0 ->
8              From ! {ok_to_write, Ref},
9              loop(Rs, Ws+1) ;
10
11         end_read   -> loop(Rs-1, Ws) ;
12
13         end_write  -> loop(Rs, Ws-1)
14     end.
```

Is it a fair solution? Unfair for writers

Fair Readers and Writers


```
1  loop() ->
2      receive
3          {start_read, From, Ref} ->
4              From ! {ok_to_read, Ref},
5              loop_read(1),
6              loop();
7
8          {start_write, From, Ref} ->
9              From ! {ok_to_write, Ref},
10             receive
11                 end_write -> loop()
12             end
13     end.
```

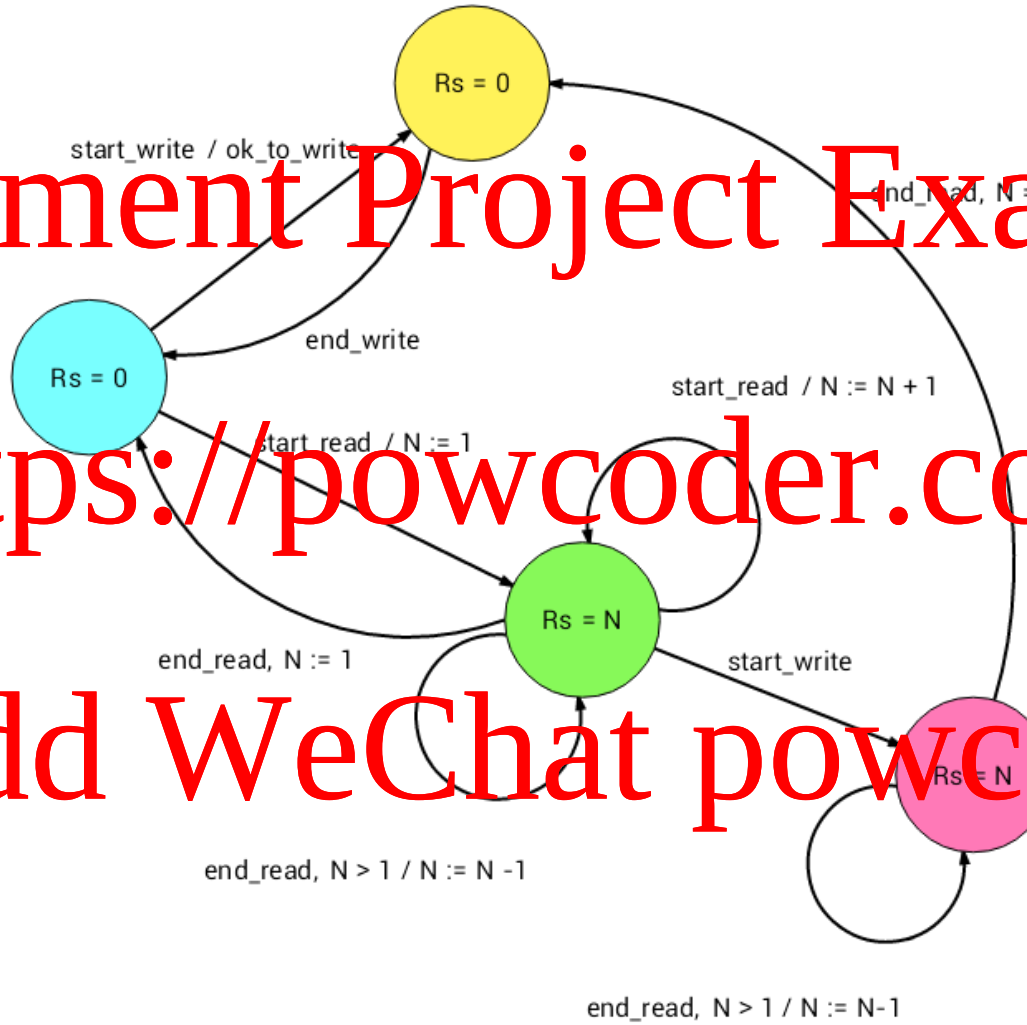
Fair Readers and Writers

```
1  loop_read(0) -> ok ;
2  loop_read(Rs) ->
3      receive
4          {start_read, From, Ref} ->
5              From ! {ok_to_read, Ref},
6              loop_read(Rs+1) ;
7
8          end_read -> loop_read(Rs-1) ;
9
10         {start_write, From, Ref} ->
11             [ receive end_read -> ok end
12               || _ <- lists:seq(1,Rs) ],
13             From ! {ok_to_write, Ref},
14             receive
15                 end_write -> ok
16             end
17     end.
```


- At top-level `loop` relies on the fairness property of Erlang (i.e. the oldest message that matches any guard is processed)
- Function `loop_read` implements fairness
- Line `[ receive end_read ->ok end || _ <- lists:seq(1,Rs) ]` performs as many receive as the number Rs

Fair Readers and Writers

- A FSM that describes its behavior



- Format of events:

`<received event>, <condition> / <triggered event>`