# Concurrent Programming: JR Language

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# JR

- JR — academic programming language for concurrency
- Extension of Java
- Advantage: Adds many expressive message passing primitives
- Disadvantage: Java is already complicated, JR is even more
- Lab 3 is based on JR

# Hello, World!

```
import edu.ucdavis.jr.JR;

public class Hello {
    public static void main (String[] args) {
        System.out.println ("Hello, world!");
    }
};
```

# Hello, World!

```
import edu.ucdavis.jr.JR;

public class Hello {
    public static void main (String[] args) {
        System.out.println ("Hello, world!");
    }
};
```

**Imports JR functions**

# Hello, World!

```
import edu.ucdavis.jr.JR;

public class Hello {
    public static void main (String[] args) {
        System.out.println ("Hello, world!");
    }
};
```

**Imports JR functions**

Save to `Hello.jr`

```
$ jr Hello
Hello, world!
```

# Compilation issues

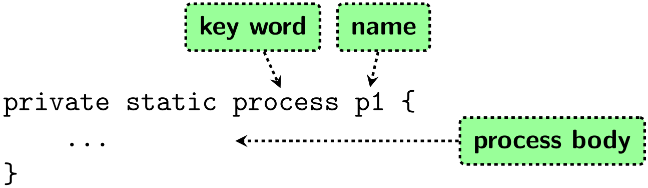
- JR compiles all `*.jr` files in your directory.
- Their contents must match their file names.

# Processes

```
private static process p1 {
    ...
}
```

- Process that runs concurrently to everything else.

# Processes



key word

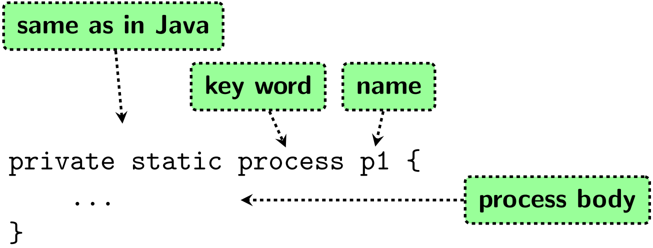
name

```
private static process p1 {
    ...
}
```

process body

- Process that runs concurrently to everything else.

# Processes



same as in Java

key word

name

```
private static process p1 {
    ...
}
```

process body

- Process that runs concurrently to everything else.

# Channels

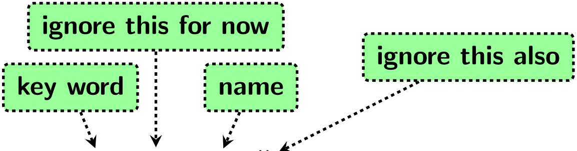
```
private static op void c1 ();
```

# Channels

**key word** **name**

```
private static op void c1 ();
```

# Channels



ignore this for now

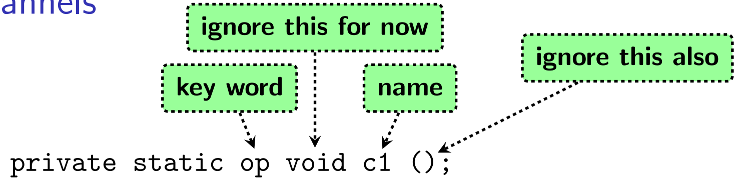
key word

name

ignore this also

```
private static op void c1 ();
```

# Channels



ignore this for now

ignore this also

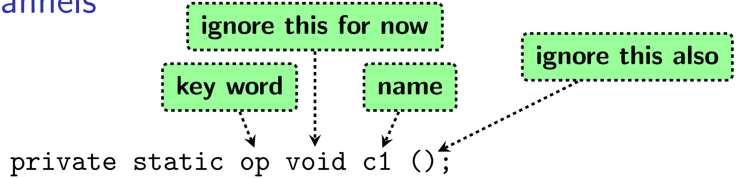
key word

name

```
private static op void c1 ();
```

- Channel, which can be used to send and receive messages.
- Many processes can send and receive on the same channel.
- Messages sent to a channel are queued.

# Channels



ignore this for now

ignore this also

key word

name

```
private static op void c1 ();
```

- Channel, which can be used to send and receive messages.
- Many processes can send and receive on the same channel.
- Messages sent to a channel are queued.

Sending and receiving:

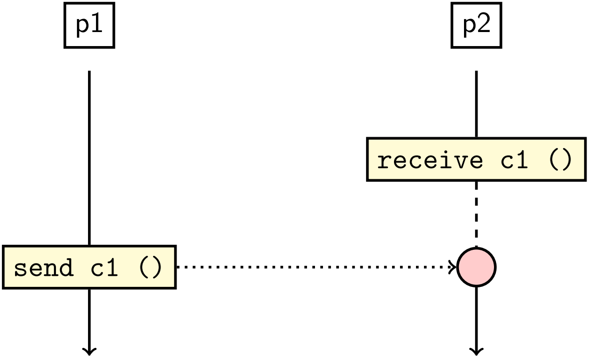
```
send c1 ();

receive c1 ();
```

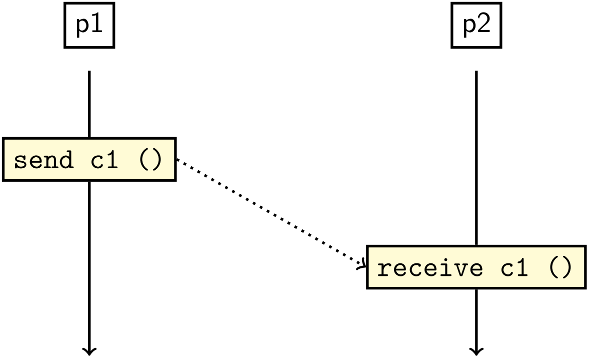
# By the way

In JR use `JR.nap()` instead of `Thread.sleep()`.

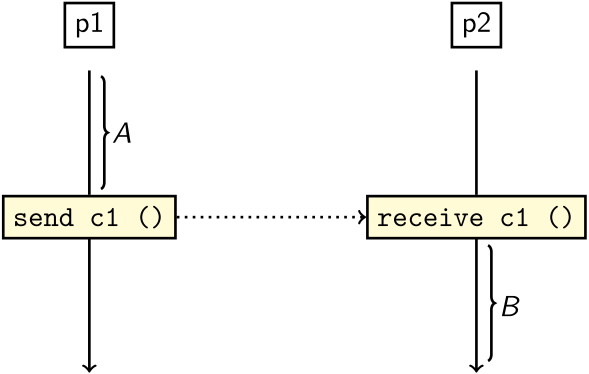
# Message send



# Message send (cont.)



# Message send (cont.)



- Send and receive ensure that actions in $A$ are executed before actions in $B$.

# And one more thing

# And one more thing

- JR has deadlock detection.
- When deadlock occurs, your program will exit.

# Summary

- Hello, compilation (and issues)
- Channels
- Sending end receiving messages
- Deadlock detection

# Static, non-static

## Static in Java

| | |
|---|---|
| static | Global, can refer only to other static things. |
| non-static | Belongs to an object of a class. |

- Variables (fields)
- Methods

## Static in JR

# Static, non-static

## Static in Java

static Global, can refer only to other static things.

non-static Belongs to an object of a class.

- Variables (fields)
- Methods

## Static in JR

- Same thing!
- Channels, channel references, etc.

# Static, non-static

**non-static channel**

```
private op void c1 ();
```

```
public static void main (String[] args) {
    send c1 ();
}
```

# Static, non-static

**non-static channel**

```
private op void c1 ();
```

```
public static void main (String[] args) {
    send c1 ();
}
```

**non-static operation** `op void c1()` **cannot be referenced from a static context**

# Static, non-static (cont.)

```
public class Static {
    private op void c1 ();

    private process p1 {
      // ...
    }

    public static void main (String[] args) {
        Static s = new Static ();
        send s.c1 ();
    }
};
```

**Non-static channels and processes are created together with an object.**

# Static, non-static (cont.)

When does a non-static process start running?

# Static, non-static (cont.)

```
public class Static {
    private op void c1 ();

    private process p1 {
      // ...
    }

    public static void main (String[] args) {
        Static s = new Static ();
        send s.c1 ();
    }
};
```

**Process `p1` starts running as soon as the object's constructor has finished.**

**Non-static channels and processes are created together with an object.**

# Array of processes

```
private static process p1 ((int i = 0; i < 10; ++i)) {
    // ...
}
```

# Array of processes

**10 processes doing the same thing.**

```
private static process p1 ((int i = 0; i < 10; ++i)) {
    // ...
}
```

# How to create processes?

- Use array of processes
- Create an object with (non-static) processes

# How to create processes?

- Use array of processes
- Create an object with (non-static) processes
- Recommended: Create an object with exactly one non-static process

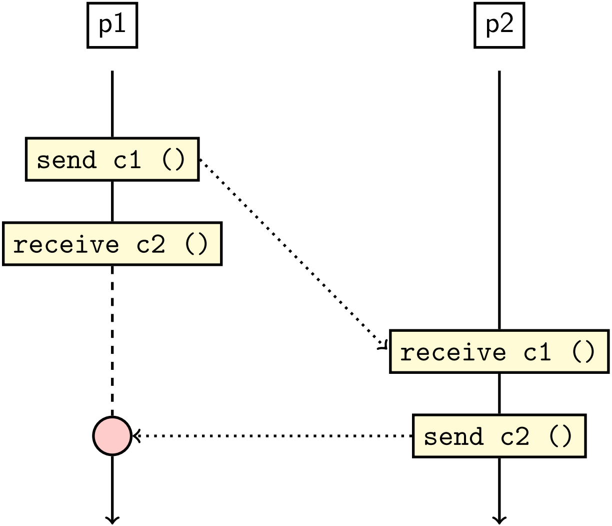
# Rendez-vous

```
private static op void c1 ();
private static op void c2 ();

private static process p1 {
    // some code
    send c1 ();
    receive c2 ();
    // more code
}

private static process p2 {
    // some code
    receive c1 ();
    send c2 ();
    // more code
}
```

# Rendez-vous (cont.)



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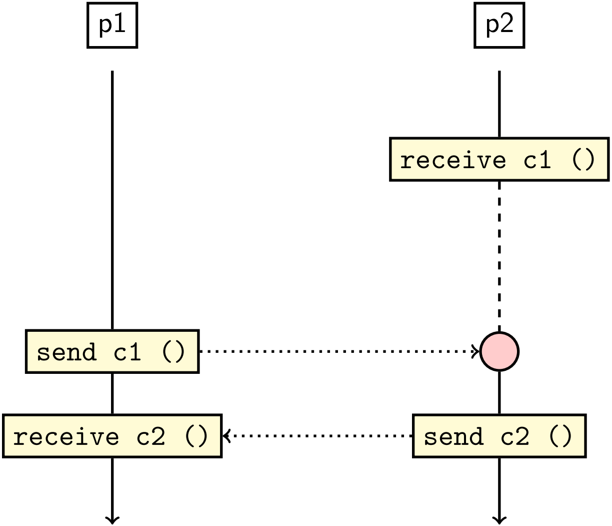
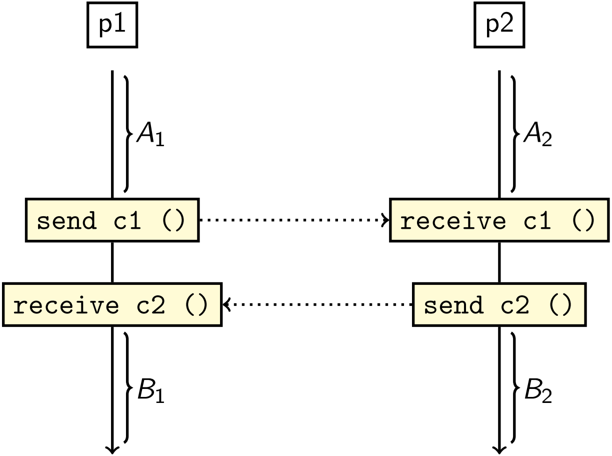


# Rendez-vous (cont.)



- This pattern ensures that actions from $A_1$ occur before actions from $B_2$ and actions from $A_2$ occur before actions from $B_1$.

# Rendez-vous (cont.)

- It is possible to implement rendez-vous (RDV) using asynchronous send and two channels.
- JR provides also direct support for rendez-vous.

# Call

```
private static op void c1 ();

private static process p1 {
    // some code
    call c1 ();
    // more code
}

private static process p2 {
    // some code
    receive c1 ();
    // more code
}
```

# Call

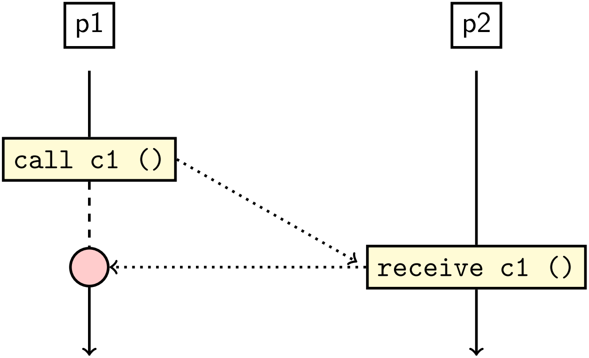
```
private static op void c1 ();

private static process p1 {
    // some code
    call c1 ();
    // more code
}

private static process p2 {
    // some code
    receive c1 ();
    // more code
}
```

`call` **will wait until the other process performs the receive.**

# Call (cont.)



p1

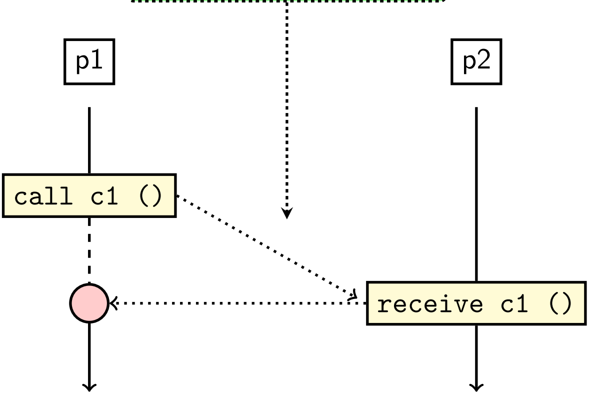
p2

call c1 ()

receive c1 ()

# Call (cont.)

`call` **provides rendezvous in JR.**



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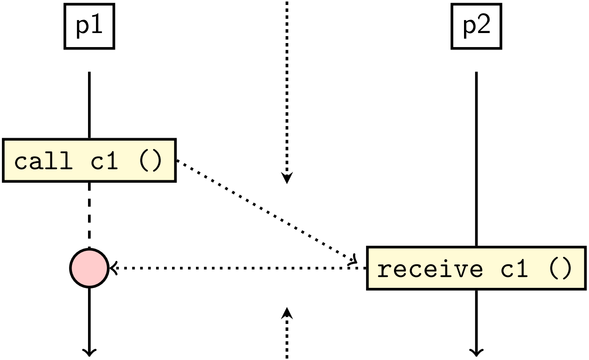
# Call (cont.)

`call` **provides rendezvous in JR.**



p1

p2

call c1 ()

receive c1 ()

**Both** `call` **and** `receive` **will wait if the other one is not ready.**

# Summary

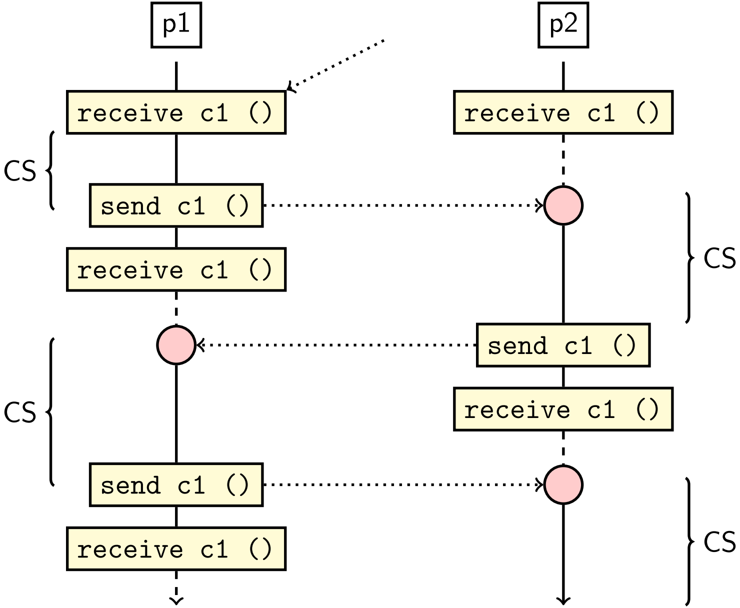
- Static/non-static channels (and processes)
- Arrays of processes
- Rendez-vous using two messages
- The `call` statement (gives us RDV directly)

# Puzzle

```
private static op void c1 ();

private static process p1 {
    for (int i = 0; i < 10; ++i) {
        receive c1 ();
        // Some code
        send c1 ();
    } }
private static process p2 {
    for (int i = 0; i < 10; ++i) {
        receive c1 ();
        // Some code
        send c1 ();
    } }
public static void main (String[] args) {
    send c1 ();
}
```

# Puzzle (cont.)


p1
p2
receive c1 ()
receive c1 ()
CS
send c1 ()
CS
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# Semaphore notation

```
private static sem s1 = 1;

private static process p1 {
    for (int i = 0; i < 10; ++i) {
        P (s1);
        // Critical section
        V (s1);
    } }
```

# Semaphore notation

**Same as defining a channel and sending a message to it.**

```
private static sem s1 = 1;

private static process p1 {
    for (int i = 0; i < 10; ++i) {
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        V (s1);
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# Semaphore notation

**Same as defining a channel and sending a message to it.**

```
private static sem s1 = 1;

private static process p1 {
    for (int i = 0; i < 10; ++i) {
        P (s1);
        // Critical section
        V (s1);
    } }
```

**Same as** `receive s1 ()`

**Same as** `send s1 ()`

# Channels with data

```
private static op void c1 (int);

private static process p1 {
    send c1 (5);
}

private static process p2 {
    int a;
    receive c1 (a);
    System.out.println ("Received message: " + a);
}
```

# Channels with data

**Each message will contain an** `int`

```
private static op void c1 (int);

private static process p1 {
    send c1 (5);
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private static process p2 {
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}
```

# Channels with data

**Each message will contain an** `int`

```
private static op void c1 (int);
```

```
private static process p1 {
    send c1 (5);
}
```

**Sending** `5` **over the channel**

```
private static process p2 {
    int a;
    receive c1 (a);
    System.out.println ("Received message: " + a);
}
```

`receive` **takes a variable and binds it to the received value**

# Channels with data (cont.)

```
private static op void c1 (type1, type2, ...);
```

# Channels with data (cont.)

**Possible to define a channel taking many values. Syntax — like method declaration.**

```
private static op void c1 (type1, type2, ...);
```

# Channels — queues

```
private static op void c1 (int);

public static void main (String[] args) {
    int a;
    send c1 (3);
    send c1 (4);
    send c1 (2);
    send c1 (7);
    for (int i = 0; i < 4; ++i) {
        receive c1 (a);
        System.out.println ("Received message: " + a);
    }
}
```

# Summary

- Semaphores using message passing
- Channels with data
- Using channels as queues

# op body

```
private static op void c1 ();

private static void c1 () {
    System.out.println ("Called c1");
}
```

# op body

**Method with the same name as a channel gets called every time a message is sent to the channel.**

```
private static op void c1 ();

private static void c1 () {
    System.out.println ("Called c1");
}
```

# op body

Method with the same name as a channel gets called every time a message is sent to the channel.

```
private static op void c1 ();

private static void c1 () {
    System.out.println ("Called c1");
}
```

Each time a message is sent a separate process is created to execute the body.

# op body

**Method with the same name as a channel gets called every time a message is sent to the channel.**

**It is not possible to receive on this channel.**

```
private static op void c1 ();

private static void c1 () {
    System.out.println ("Called c1");
}
```

**Each time a message is sent a separate process is created to execute the body.**

# op body (cont.)

- It is possible to write the declaration and definition of an `op` together.
- `call` on a channel serviced like this will wait until the method finishes.
- `op` bodies are not so useful (many instances can execute at the same time)

# Return type

```
private static op int c1 (int);

private static int c1 (int x) {
    return x + 1;
}

public static void main (String[] args) {
    int y = c1 (4);
    System.out.println ("y = " + y);
}
```

# Return type

**Return type**

```
private static op int c1 (int);

private static int c1 (int x) {
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}

public static void main (String[] args) {
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}
```

# Return type

**Return type**

```
private static op int c1 (int);

private static int c1 (int x) {
    return x + 1;
}
```

**Alternative notation to** `call`

```
public static void main (String[] args) {
    int y = c1 (4);
    System.out.println ("y = " + y);
}
```

# Ways of calling

- `send` + `receive`: Asynchronous message
- `call` + `receive`: RDV, no return value
- `call` + `op` body: synchronous call, return value possible

# `inni` statement

Is it possible to `receive` and still return a value?

# `inni` statement

Is it possible to `receive` and still return a value?
Yes — using `inni`, which is a (very large) extension of `receive`.

# inni statement (cont.)

### inni statement

- More powerful receive
- Waits on many channels at the same time
- Can send a ‘return message’ to the calling process
- Has a non-blocking variant

# inni statement syntax

```
inni int c1(int n) {
    cntr += n;
    return cntr;
} [] void c2(int n) {
    cntr += n;
}
```

# inni statement syntax

**Receive simultaneously on** c1 **and** c2 **and execute the corresponding body of the statement.**

```
inni int c1(int n) {
    cntr += n;
    return cntr;
} [] void c2(int n) {
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```

# inni statement syntax

**key word**

**Receive simultaneously on `c1` and `c2` and execute the corresponding body of the statement.**

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```
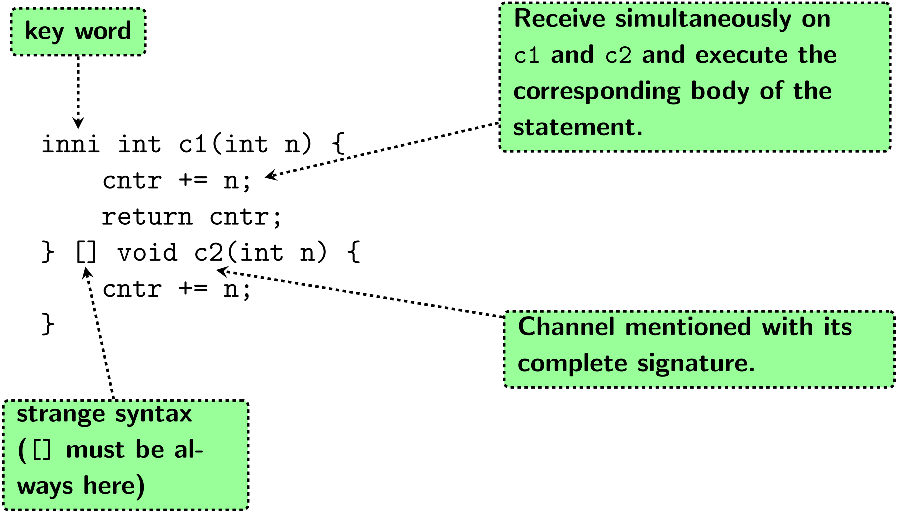

**strange syntax ([] must be always here)**

# inni statement syntax



key word

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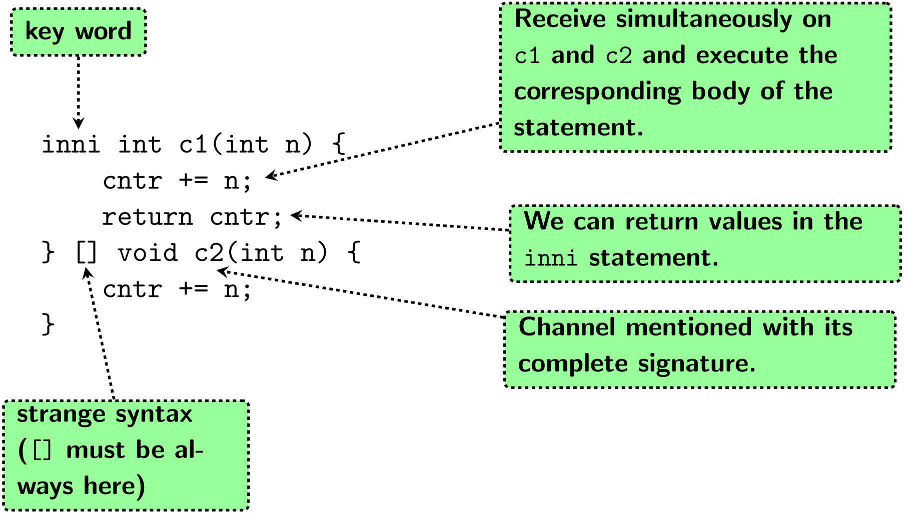
Receive simultaneously on c1 and c2 and execute the corresponding body of the statement.

Channel mentioned with its complete signature.

strange syntax ([] must be always here)

# inni statement syntax



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}
```

**Receive simultaneously on `c1` and `c2` and execute the corresponding body of the statement.**

**We can return values in the `inni` statement.**

**Channel mentioned with its complete signature.**

**strange syntax (`[]` must be always here)**

# Non-blocking receive

# Non-blocking receive

**`inni` statement with an `else` branch will check if there is a message in the queue (and receive it).**

```
inni void c() {
  received = true;
} [] else {
  // do nothing
}
```

# Summary

- Servicing channels with `op` body.
- `inni` statement
- Non-blocking receive

# Reply statement

reply can occur only inside of an inni statement.

```
int x;

inni int c1() {
    reply x;
    // do something more
}

// ...

int y = c1 ()
```

# Reply statement

`reply` can occur only inside of an `inni` statement.

```
int x;

inni int c1() {
    reply x;
    // do something more
}

// ...

int y = c1 ()
```

**The reply will come before the `inni` statement terminates.**

# Forward statement

`forward` can also occur only inside of an `inni` statement.

```
int x;

inni int c1() {
    forward c2(x);
}

// ...

inni int c2(int z) {
    return z+2;
}

// ...

int y = c1 ()
```

# Forward statement

`forward` can also occur only inside of an `inni` statement.

```
int x;

inni int c1() {
    forward c2(x);
}
```

**`forward` calls channel `c2` and continues immediately.**

```
// ...

inni int c2(int z) {
    return z+2;
}
```

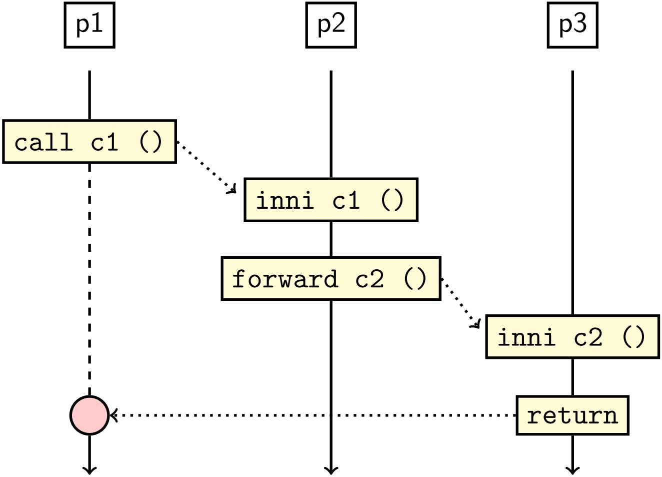
**Channel `c2` gets a message with a ‘return address’ still pointing at the original call.**

```
// ...

int y = c1 ()
```

**The reply from the second `inni` will arrive directly here.**

# Forward statement



# Server process

```
process p1 {
  while (true) {
    inni int c1 (boolean x) {
      // ...
    } [] bool c2 () {
      // ...
    } // ...
  }
}
```

# Server process

```
process p1 {
  while (true) {
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      // ...
    } // ...
  }
}
```

**Branches of `inni` are critical sections that operate on private data.**

**Channels are operations that are called by external processes, serviced in order.**

# Server process (cont.)

## Loop with `inni`

- Branches of `inni` are critical sections.
- Private data is accessed sequentially by critical sections.
- Channels are operations that are called by external processes, serviced in order.

# Server process (cont.)

## Loop with `inni`

- Branches of `inni` are critical sections.
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- Channels are operations that are called by external processes, serviced in order.

## Monitor

- Operations of a monitor contain critical sections.
- Private data is accessed sequentially by critical sections.
- Operations that are called by external processes, serviced in order.
- Some operations may block on condition variables and be woken up with signals.

# Server process (cont.)

### Loop with `inni`

- Branches of `inni` are critical sections.
- Private data is accessed sequentially by critical sections.
- Channels are operations that are called by external processes, serviced in order.
- ???

### Monitor

- Operations of a monitor contain critical sections.
- Private data is accessed sequentially by critical sections.
- Operations that are called by external processes, serviced in order.
- Some operations may block on condition variables and be woken up with signals.

# Allocator in Java

```
int allocate (int n) {
  lock.lock ();
  try {
    while (units < n) added.await ();
    return take(n);
  } finally {
    lock.unlock();
  } }
void release (int us) {
  lock.lock ();
  try {
    units += us;
    added.signalAll();
  } finally {
    lock.unlock();
  } }
```

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  } }
```

**Not enough elements, we have to wait on a condition variable.**

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**Not enough elements, we have to wait on a condition variable.**

**We need to recheck the condition whenever we wake up.**

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  try {
    units += us;
    added.signalAll();
  } finally {
    lock.unlock();
  } }
```

**Not enough elements, we have to wait on a condition variable.**

**We need to recheck the condition whenever we wake up.**

**Perhaps somebody is waiting; wake everyone up.**

# Allocator in JR

```
public static op int allocate (int);
public static op void release (int);

private static int units = 0;
private static op int repq (int);
```

# Allocator in JR

Two channels used by clients

```
public static op int allocate (int);
public static op void release (int);

private static int units = 0;
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Counter of available resources

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Two channels used by clients

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public static op int allocate (int);
public static op void release (int);

private static int units = 0;
private static op int repq (int);
```

Counter of available resources

Internal channel for keeping waiting clients

# Allocator in JR

```
private static process p1 {
    while (true) {
        inni int allocate(int n) {
            if (units < n)
                forward repq(n);
            else
                units -= n;
                return n;
        } [] void release(int us) {
            units += us;
            while (repq.length() > 0)
                inni int repq(int n) {
                    forward allocate(n);
                }
        }
    } }
```

# Allocator in JR

**If there are not enough elements, push the request to the waiting channel.**

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Equivalent of `signalAll`.

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```

**Equivalent of** `signalAll`**.**

**We jump to the beginning of** `allocate` **here!.**

# st clauses

```
inni int allocate(int n) st n <= units {
  units -= n;
  return n;
} [] void release(int n) {
  units += n;
}
```

# st clauses

**The message will be consumed only if the condition is satisfied.**

```
inni int allocate(int n) st n <= units {
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# st clauses

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}
```

**How much simpler it is!**

# Summary

- `reply` statement
- `forward` statement
- Server processes
- `st` clauses

# Message priorities

```
inni int allocate(int n) st n <= units by n {
  units -= n;
  return n;
} [] void release(int n) by n {
  units += n;
}
```

# Message priorities

**Messages with lowest `n` will be handled first.**

```
inni int allocate(int n) st n <= units by n {
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# Message priorities

**Messages with lowest `n` will be handled first.**

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  units -= n;
  return n;
} [] void release(int n) by n {
  units += n;
}
```

**Priorities don’t work accross branches!**

# Message priorities (cont.)

```
inni int allocate(int n) st n <= units &&
                 release.length() == 0 {
  units -= n;
  return n;
} [] void release(int n) by n {
  units += n;
}
```

# Message priorities (cont.)

**Receive only if there are no messages in the other channel (useless in this example).**

```
inni int allocate(int n) st n <= units &&
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**Checking `length()` of a channel is safe here.**

# Message priorities (cont.)

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inni int allocate(int n) st n <= units &&
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}
```

**Checking any other shared resource is not.**

**Checking `length()` of a channel is safe here.**

# Terminating processes

```
while (run) {
  inni void terminate() {
    run = false;
  } [] else {
  // some work
  }
}
```

# Terminating processes

inni **statement with an** else **branch will check if there is a message in the queue (and receive it).**

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**Terminating processes is a tricky topic.**

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while (run) {
  inni void terminate() {
    run = false;
  } [] else {
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  }
}
```

**Terminating processes is a tricky topic.**

**You will have to make it work with your program logic.**

# Capabilities (references to channels)

```
private static op void c1 ();

private static void c1 () {
    cap void () x;
    x = c1;
    receive x ();
}
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**Different syntax than `op` declarations (name comes last).**

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**Different syntax than `op` declarations (name comes last).**

```
op void c2 (cap void ());
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# Capabilities (references to channels)

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private static op void c1 ();

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    x = c1;
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```

**Different syntax than `op` declarations (name comes last).**

```
op void c2 (cap void ());
```

**Channel taking a channel reference.**

# Summary

- Message priorities
- Prioritising one channel over another
- Channel references
- `reply` statement
- `forward` statement

# Tips for the lab

## What you want to use

- `inni` statement
- `st` clauses
- `else` in the `inni` statement
- Channel references (very few places)
- Arrays of processes (probably not)

## What you probably don't need

- `reply` statement
- `forward` statement
- Message priorities (`by` clauses)