System Architecture

10 Message Passing

IPC Design & Implementation,
IPC Application, IPC Examples

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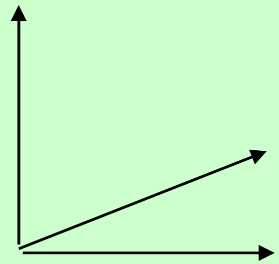
Gerd Liefländer

Agenda

- Motivation/Introduction
- Message Passing Model
- Elementary IPC
- Design Parameters for IPC
  - Synchronization
  - Addressing Modes
  - Lifetime
  - Data Transfer
  - Types of Activations (your work)



- High Level IPC
- IPC Applications
- IPC Examples

Motivation

Yet another Concept?

1. Previous mechanisms relied on shared memory ⇒ all these solutions do not work in distributed systems

2. Threads of different applications need protection ⇒ even in systems with a common RAM, because you do not want to open your protected AS for another cooperating non trusted piece of software

3. To minimize kernels some architects only offer IPC to solve
   - communication problems as well as all
   - synchronization problems

4. However, the opposite way also works, i.e. you can use semaphores to implement a message passing system

Message Passing

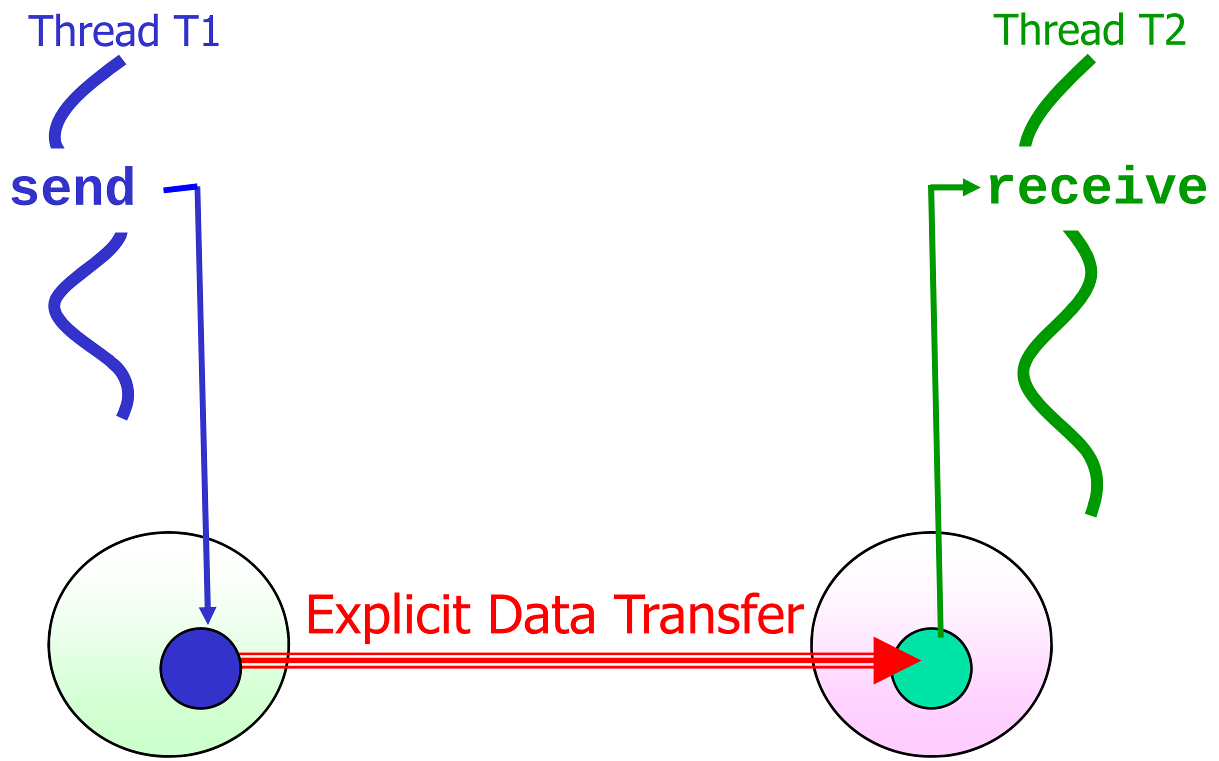
- Used for Inter-“Process” Communication (IPC)
  - Interacting threads within a distributed system
  - Interacting threads within the same computer
  - Interacting threads within the same address space
  - We expect a decreasing complexity and vice versa an increasing speedup when implementing IPC

- Application:
  - Exchange information in form of messages

- At least two primitives:
  - **send (destination, message)**
  - **receive (source, <u>message</u>)**

IPC Model

Basic Principle of Message Passing



Problems with Message Passing

- *Data inconsistency still a problem?*
- Yes, because messages can be
  - *out of order* ⇒ even if each message is consistent, the sequence of messages is not
  - *incomplete*, because receiver has not enough buffer space
  - *lost*
  - *outdated*, i.e. they no longer reflect the current state of the sender
- Each message can be an *information leak*, that's why we must control whether messages should be transferred or not

Elementary IPC

Design of Message Passing

- Elementary communication (two threads)
  - 1 Sender and 1 Receiver
- Later on:
  - Higher communication level
  - Typical applications
  - IPC examples of current operating systems

Orthogonal Design Parameters

- Connection of communicators
- Synchronization
- Addressing
- Docking of IPC objects
- Ownership
- Organization of data transfer
  - Ordering of messages
  - Format of messages (size)
  - Buffering
  - Internal scheduling
- ...

Connection

- Connection oriented

`openConnection(address)`

Tests whether receiver exists and whether he/she wants a connection with the caller

`send(message)`

`receive(message)`

`closeConnection()`

Empties message buffer and deletes connection

Connection

- Connectionless

```
send(target_address, message)
receive(source_address, message)
```

- Target is often a server
- Source is often a client

Synchronization of Sender

Unsynchronized Send (Non Blocking)	If receiver does not wait for message, *skip* message, *continue*
Asynchronous Send (Non Blocking)	If receiver does not wait for message, *deposit* message (if enough buffer place), *continue*
Synchronous Send (Blocking)	If no receiver waits for a message, *deposit* message, *wait* for receiver
In all cases:	If receiver already waits for message, *transfer* message, *continue*

Synchronization of Receiver

- Non-Blocking Receive — *Void* if there is no message (test for arrival)
- Blocking Receive — *Waits* if there is no message available
- In both cases, if message has been buffered, transfer message to receiver's AS, *continue*

Combinations of Senders/Receivers

	Non-blocking Receive	Blocking Receive
Unsynchronized Send	- *bogus* -	Sender polling
Asynchronous Send	Receiver polling	Asynchronous communication
Synchronous Send	Receiver polling	Rendezvous

Observation:
As long as asynchronous sending is used we have to provide *message buffers* (in the communication link)

Enhanced Message Passing

Sender S synchronously sends message to receiver R

What might happen to S due to many reasons?

Receiver R can be down or has already finished
⇒ Sender S would wait forever
(another example for starvation ≠ deadlock)

What to do?

Enhance communication with a timeout mechanism

Timeout

With a timeout you specify how long you want to wait until a certain event should have taken place.

Assume: Even under heavy load your partner thread should have accepted your messages within xyz ms.

⇒

Enhance your synchronous send operation as follows:

syncSend(receiver', message, xyz, result)

If receiver does not receive message within xyz ms, sender can be informed via *result*: "*missing receiver*". So it's up to the sender how to proceed (if after all).

Addressing the Communication

- Direct Addressing
  - send (TID, message)
  - *send(filter{TID}, message)*
  - receive(TID, message)
  - *receive(filter{TIDs}, message)*

- Indirect Addressing
  - send (channel identifier, message)
  - send (port identifier, message)
  - ...

Direct Addressing

- caller names partner thread explicitly or per wildcard:
  - `send(T, message)` send message to T
  - `receive(Q, message)` receive message from Q
  - `send(T1∧T2, message)`
  - `send(T1∨T2, message)` different semantics
  - `receive(*, message)` receives message from any thread

Direct Addressing

- Properties of temporary communication link
  - Links are established automatically
  - Link is associated with exactly one pair of communicating threads
  - Link can be *unidirectional* or *bi-directional* depending on the communication pattern:
    - Notification
    - Request

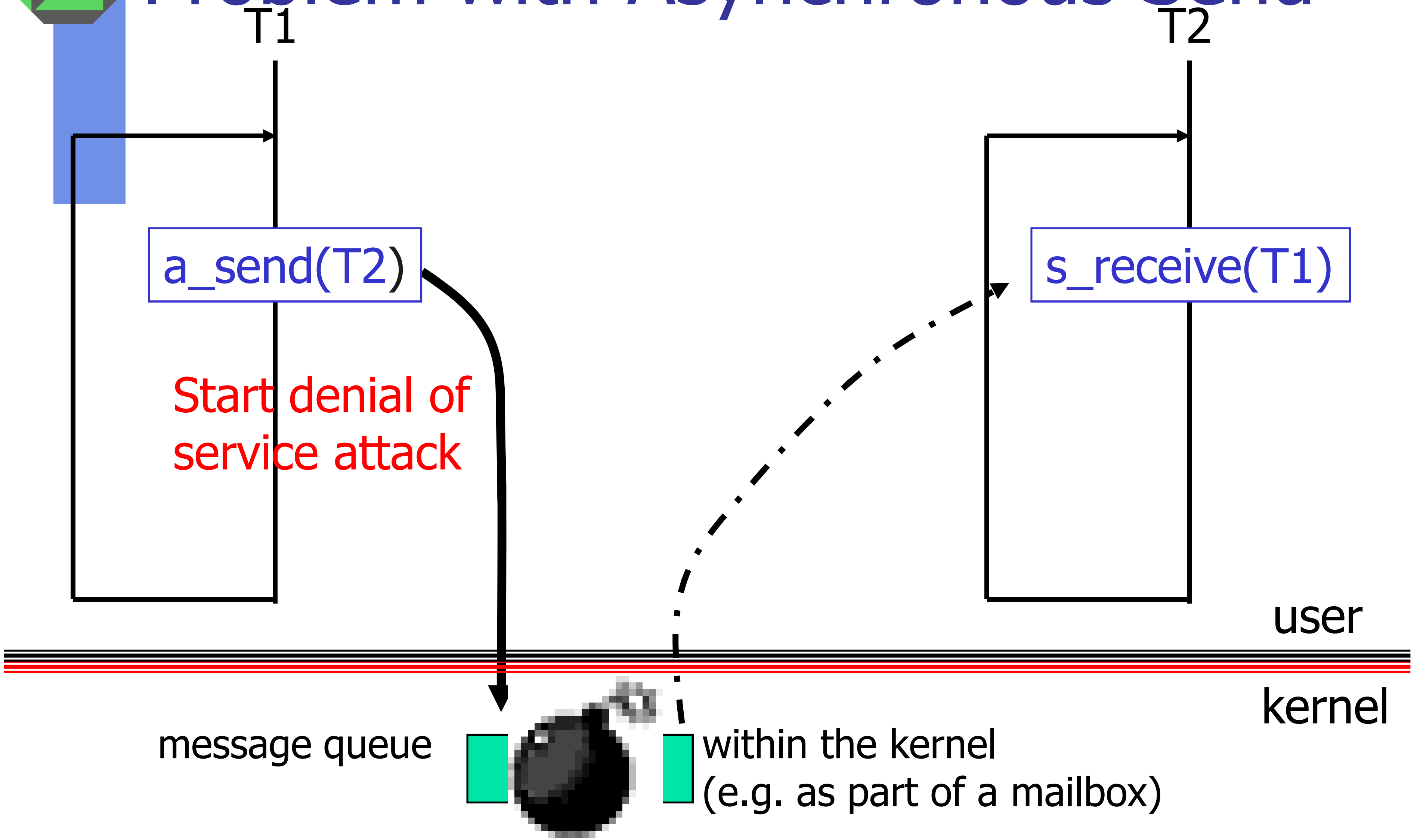
Notification

- Notification is a *one way message* from sender to receiver
- *Message transaction* ends with message delivery to receiver
- Interpreting of the message in the receiver does no longer belong to IPC

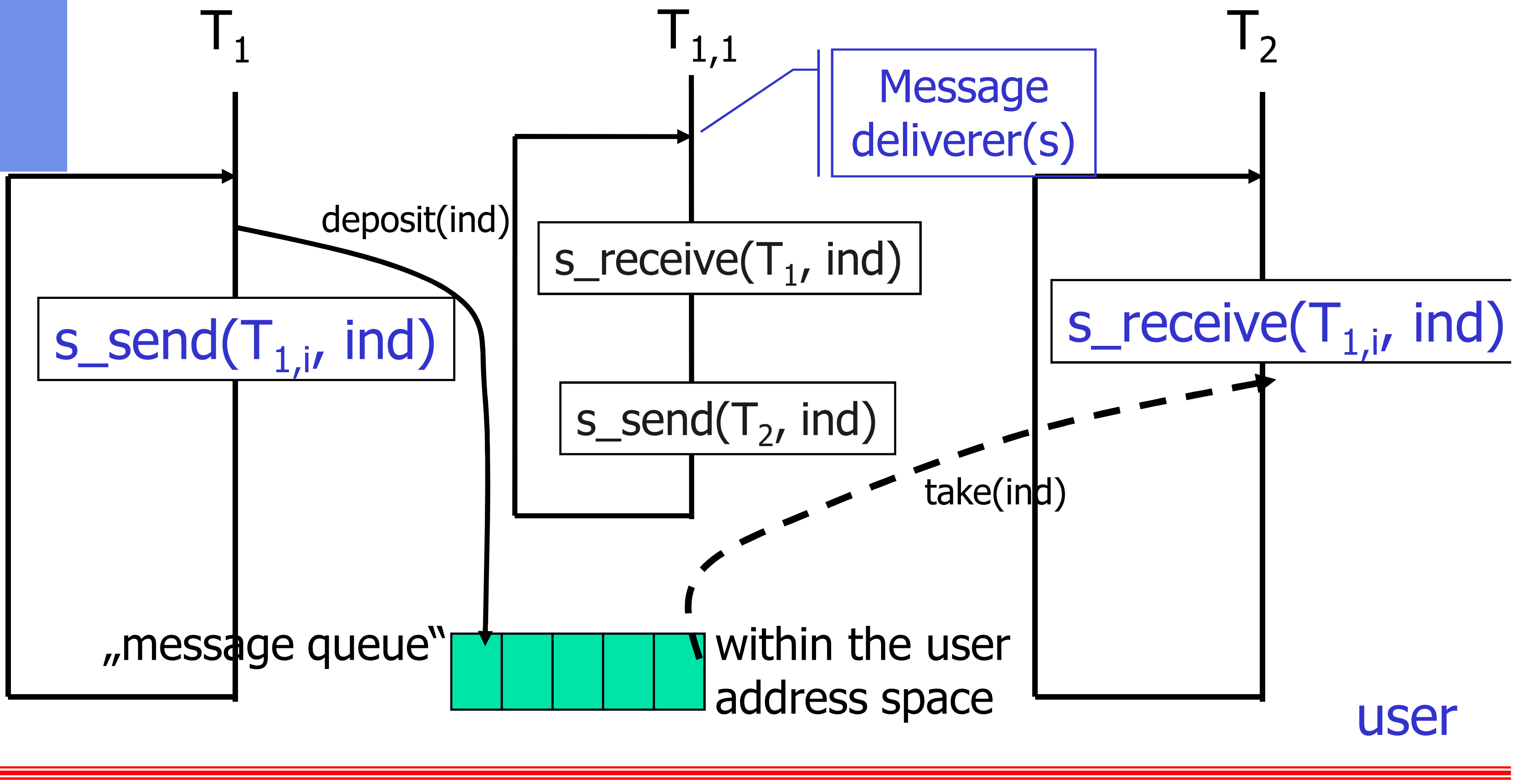
Request

- Request is a *two way message* from sender to receiver
- It starts by sending the request to the receiver and ends with an acknowledge (+ result of service) from receiver to sender
- In the mean time receiver (~server) has delivered the required service

Problem with Asynchronous Send



Asynchronous via Synchronous Send



Question: Is there a correlation between # buffer slots and # of message deliverers?

Indirect Addressing

- Messages are sent to (and received from) mailboxes, ports, channels
  - Each mailbox has a *unique id* (e.g. MBID)
  - Threads can communicate only if *sharing a mailbox*
- Properties of communication link
  - A link established only if threads share a common mailbox
  - A link can be associated with many threads
  - Each thread can share several communication links
  - A link can be both unidirectional or bi-directional.

Indirect Addressing

- Operations
  - create a new mailbox
  - send and receive messages through mailbox
  - attach and detach mailbox members
  - delete a mailbox

- Interface primitives

send(MB,*message*) : sends message to mailbox MB

receive(MB,*message*): receives message from MB

attach(MB,T): attaches thread T to MB

detach(MB,T): detaches T from MB

You can enhance attach by additional access rights etc.

Indirect Addressing

- Mailbox sharing
  - T_1, T_2, and T_3 can share a mailbox A.
  - Suppose: T_1, sends; T_2 and T_3 have previously invoked a receive at A.
  - *Who will get the message?*
- Possible Solutions
  - Type the message with an additional thread ID
  - Allow the system to select arbitrarily the receiver. Sender can be notified to which receiver the message has been delivered
- High level communication patterns often build upon mailboxes

Summary: Indirect Addressing

Advantages:

Still easy to understand, but more ***flexible*** than direct addressing

Suited for arbitrary partnerships (s≥1 sender, r≥1 receiver)

Each mailbox may provide an ***individual security policy***

Mailboxes can survive threads

Disadvantages:

More spatial overhead due to extra data structure

Potentially one additional copy of the message

What to do with attached threads if mailbox owner deletes it? (Dangling thread problem)

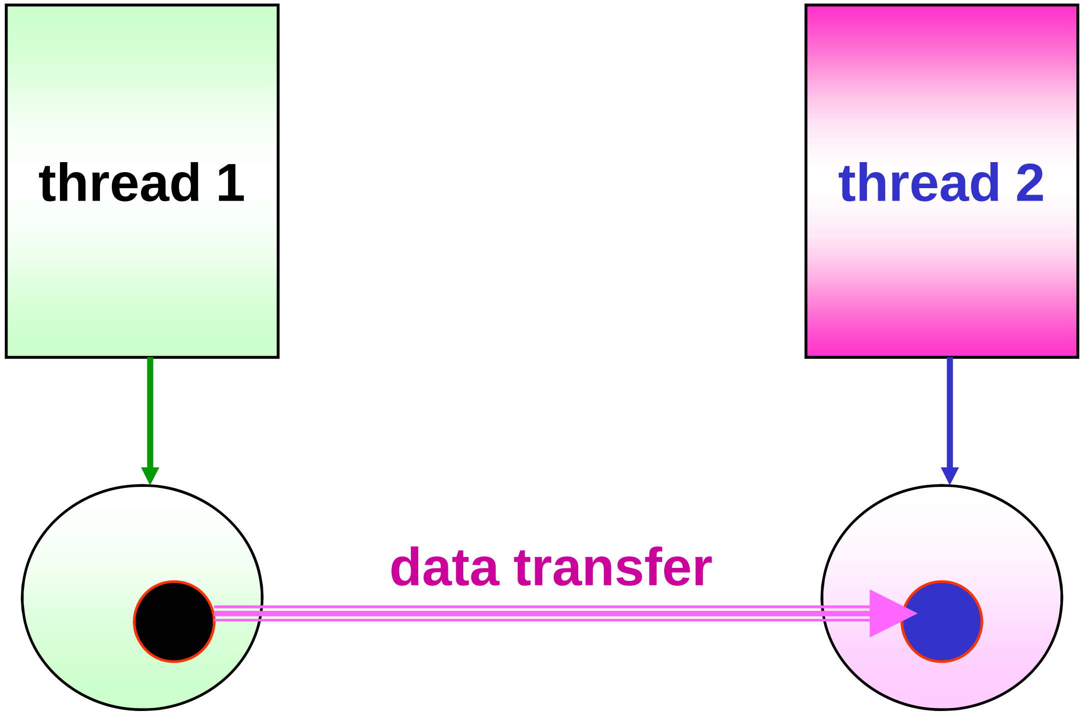
If a thread currently attached to a mailbox has to be aborted ⇒ problem of dangling messages

Docking IPC Objects

Docking = relationship of the communicating threads with the communication facility, i.e. IPC-object:

- *Dynamically*, i.e. a thread can
  - Create a new mailbox
  - Attach to and detach from a mailbox
  - Delete its mailbox
- *Statically*, i.e. thread has its IPC-object (e.g. port) only during its life

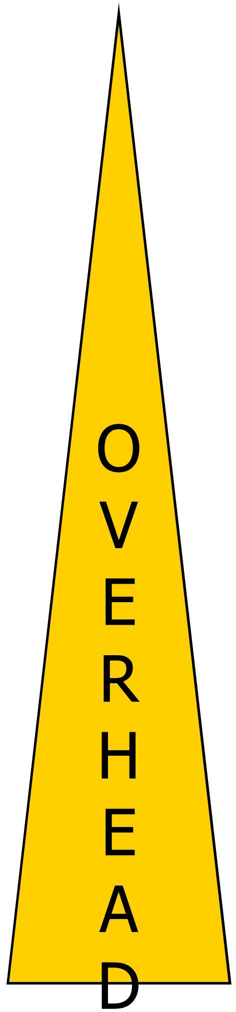
Organization of Data Transfer



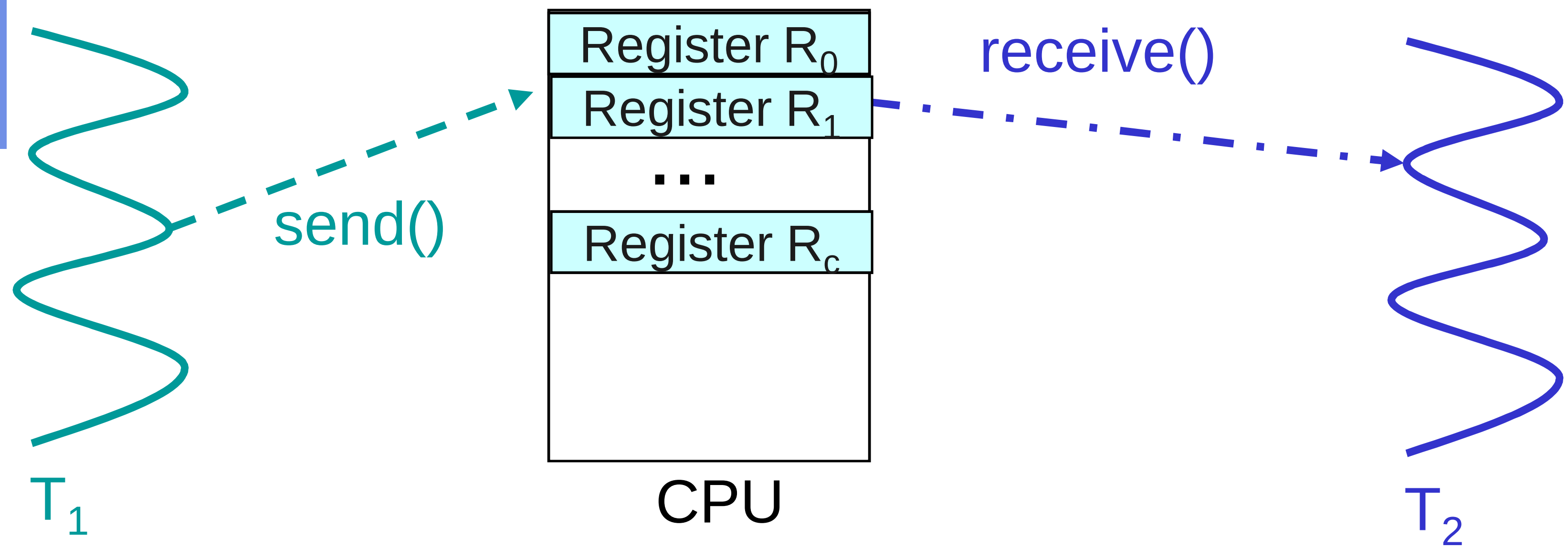
<u>Question:</u> Do we need to copy the message in each case?

Data Transfer of Messages

- Register (short messages, 0 copy)
  - Implications how to synchronize
- Shared memory (long message 0 copy)
  - Implications how to synchronize
  - Registers or kernel memory only used to transmit address(es) of message(s)
- Temporal mapping of message (1 copy)
  - Implications …???
- Kernel Buffer (2 copies)

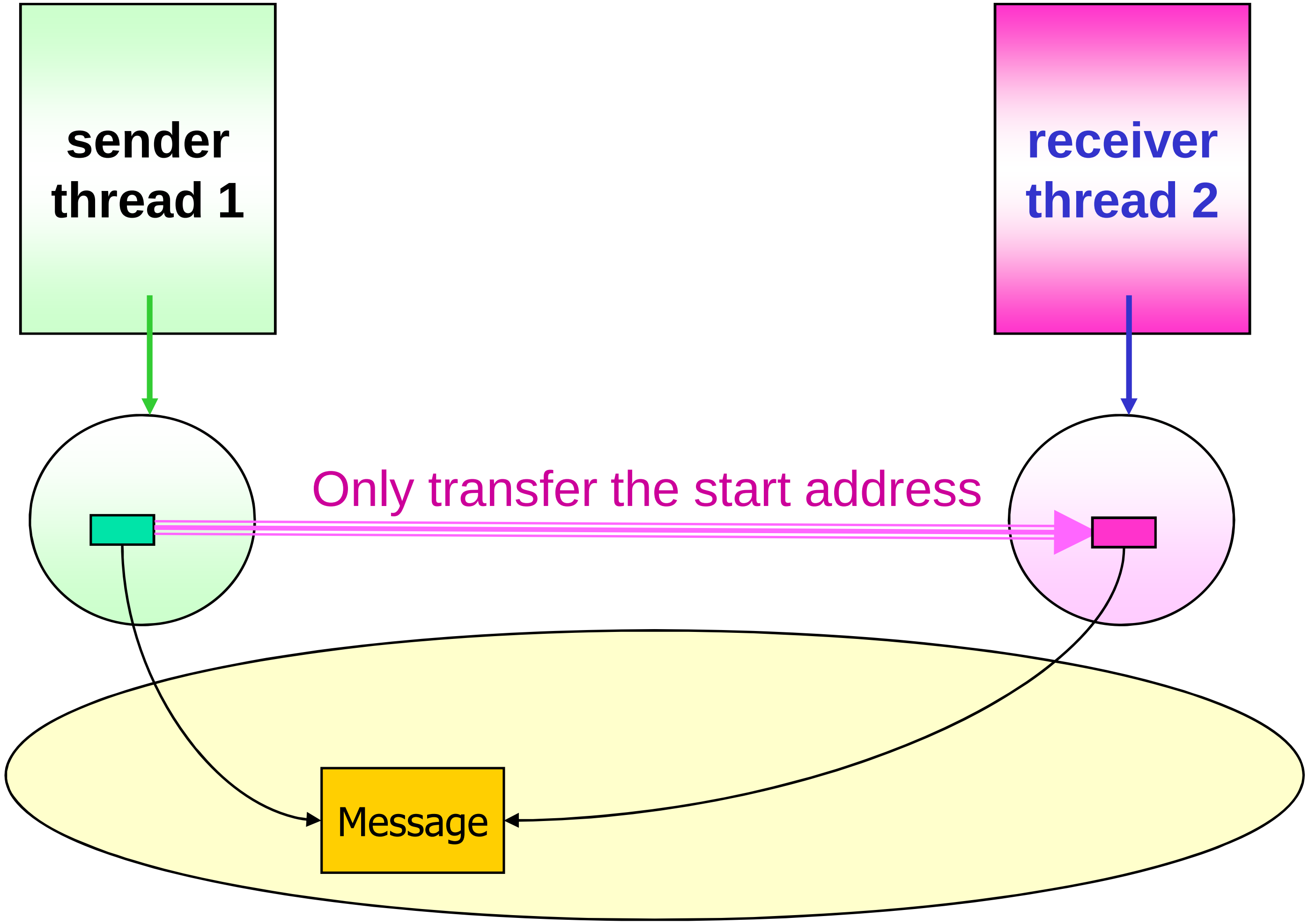


Data Transfer via Register

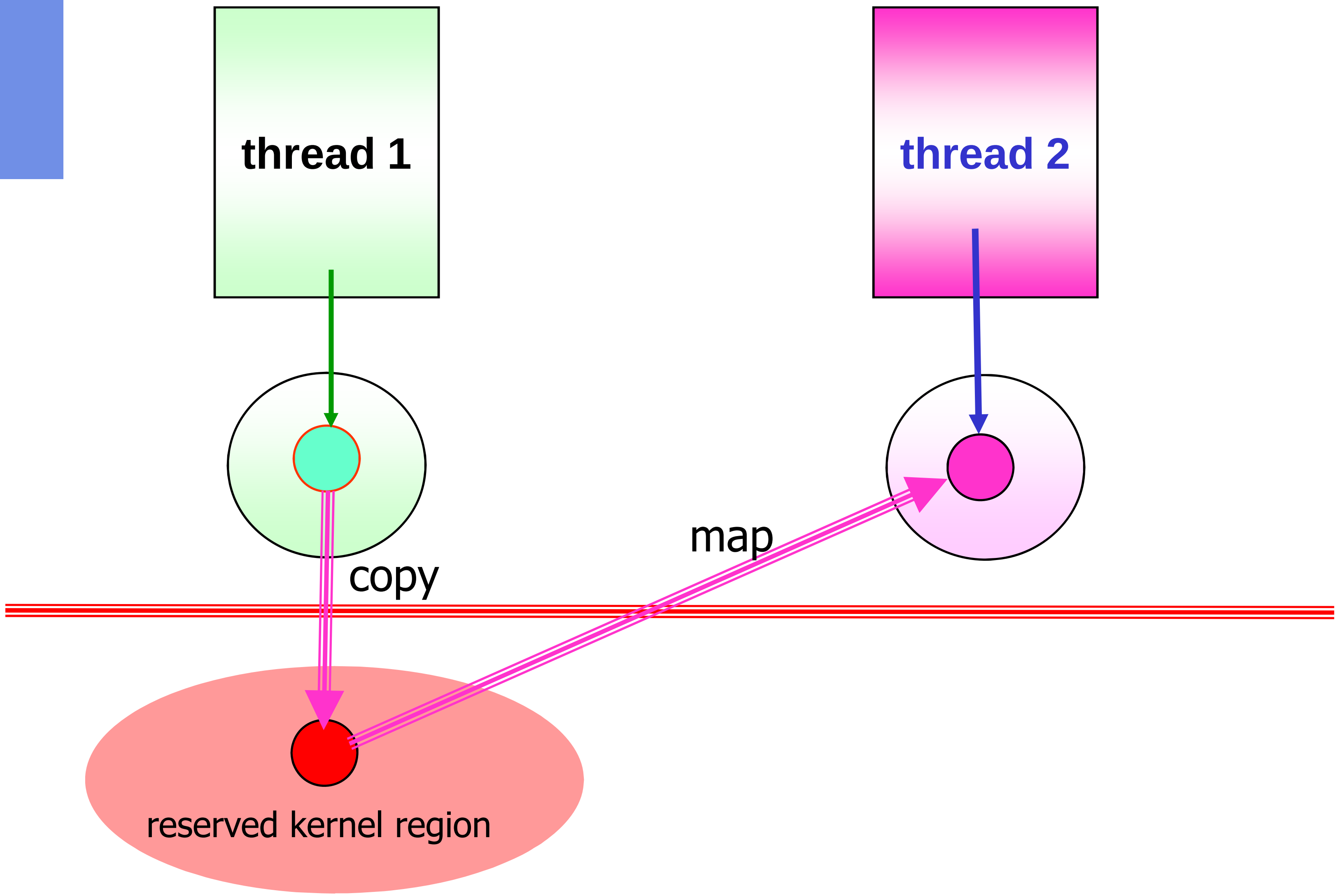


<u>Hint:</u> Discuss this proposal
Does it work for all variations?
Main advantages?
Main constraints?

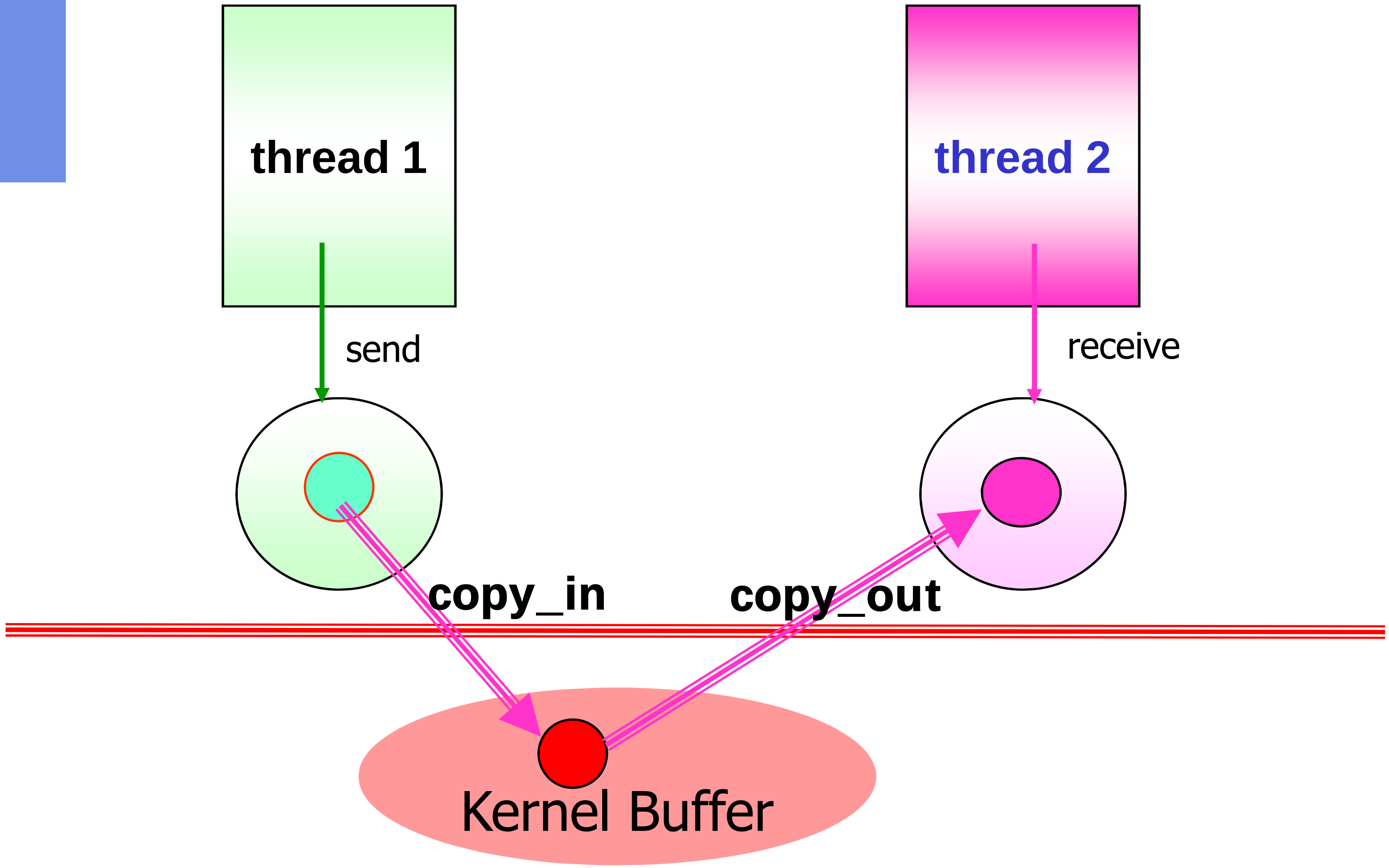
Data Transfer via Shared Memory



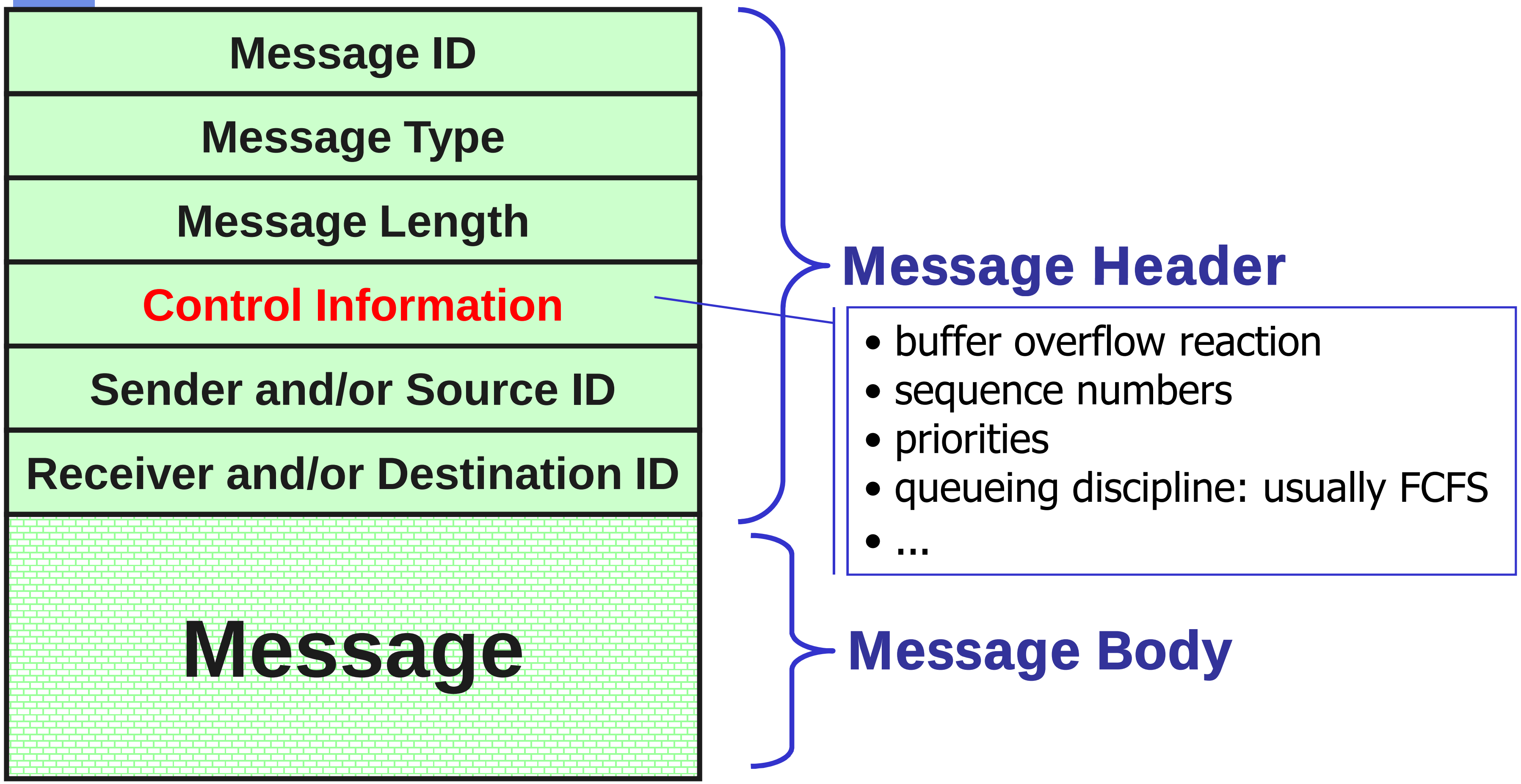
Data Transfer via Mapping



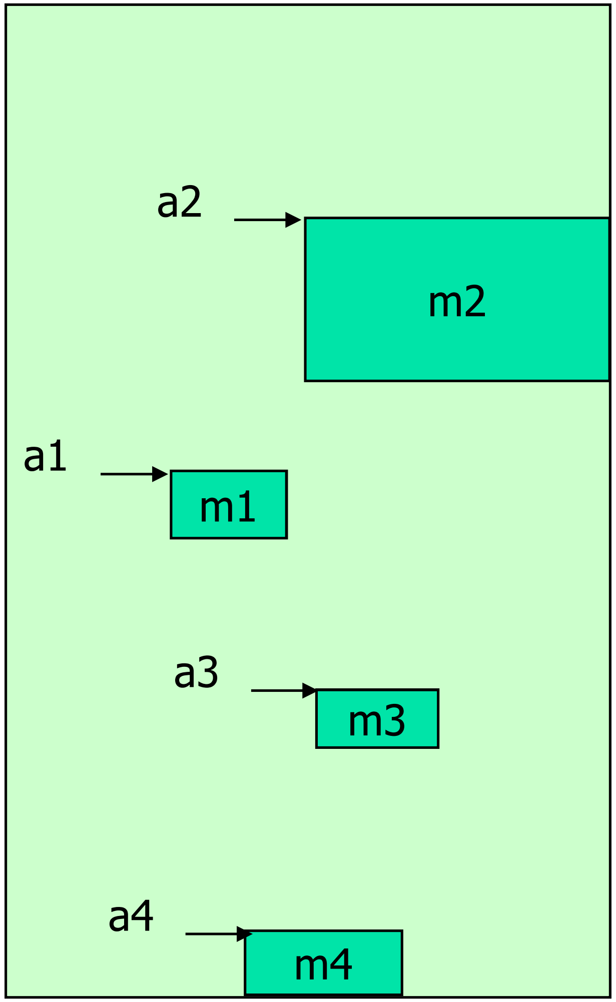
Data Transfer Via Kernel Buffer



Potential Formats of Messages



Non Contiguous Messages



Problem:
Message to be sent is scattered

<u>Approach 1:</u>
copy m1 … m4 into a buffer
send buffer to target R

<u>Solution:</u>
`send(R,<a1,a2,a3,a4>)`

Types of Communicating Activities

Homogeneous Communication

Heterogeneous Communication

Evaluate for your own

High Level IPC

Local Systems

Distributed Systems (see ST 2008)

Client Server Communication

- Local server
- Sockets
- Remote Procedure Calls
- Remote Method Invocation (Java)

Topic of the course DS

Synchronous IPC with a Server

Client

.

.

.

Request a service from a server

```
SynchSend(server, request)
SynchReceive(server, result)
```

.

.

.

Pro: No additional feature

Con: 2 system calls ⇒ ***more overhead***
If dispatching takes place between these calls ⇒ server cannot deliver its result, it is delayed

Remote Procedure Call (RPC)*

Client

.
.
.

Request a service from a server { **`RPC(Server, Request)`**

.
.
.

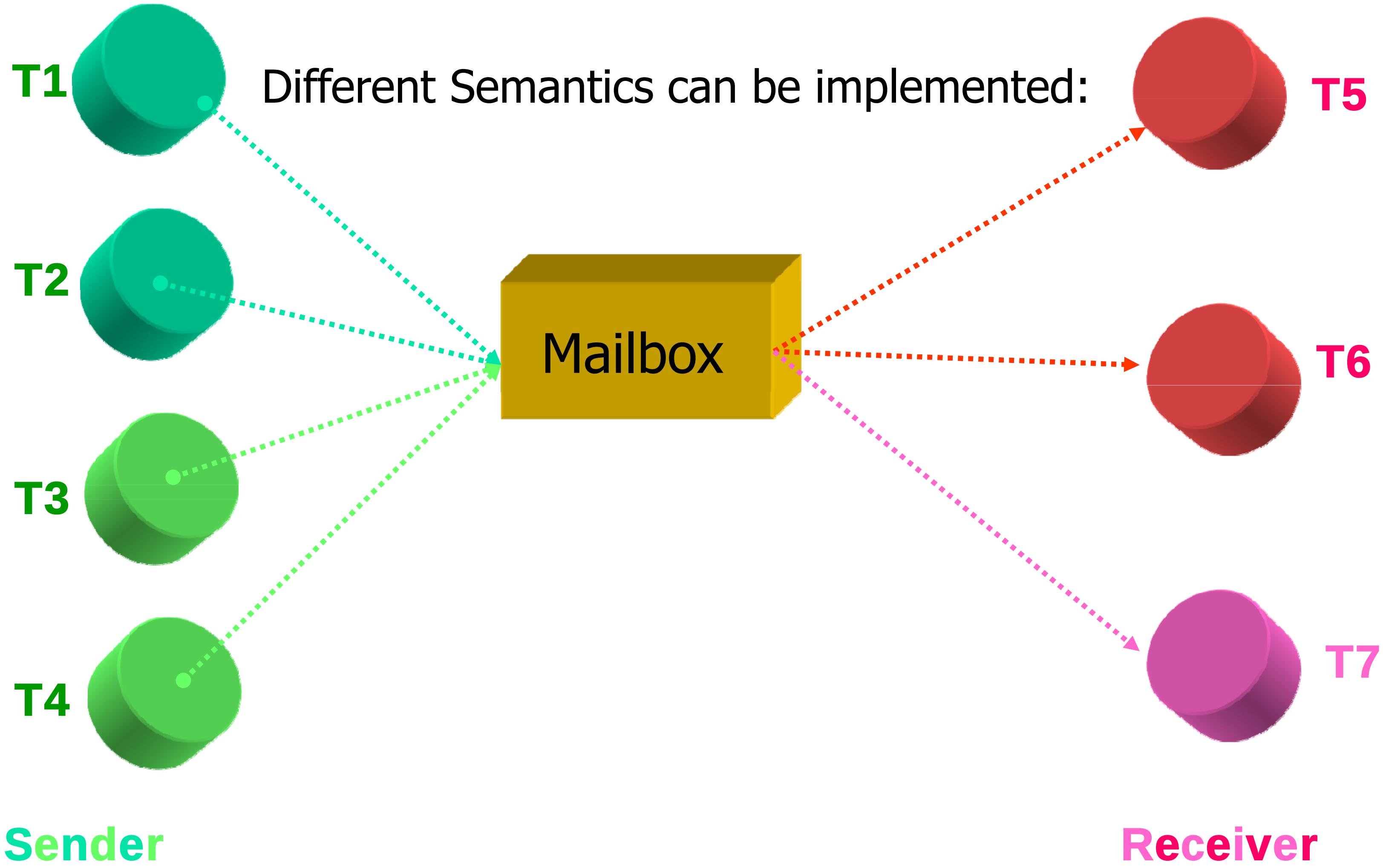
Pro: Only 1 system call, requesting sender has to wait, needed in distributed systems anyway

Con: *Additional feature*

*In local systems this IPC is called LPC

Indirect Communication

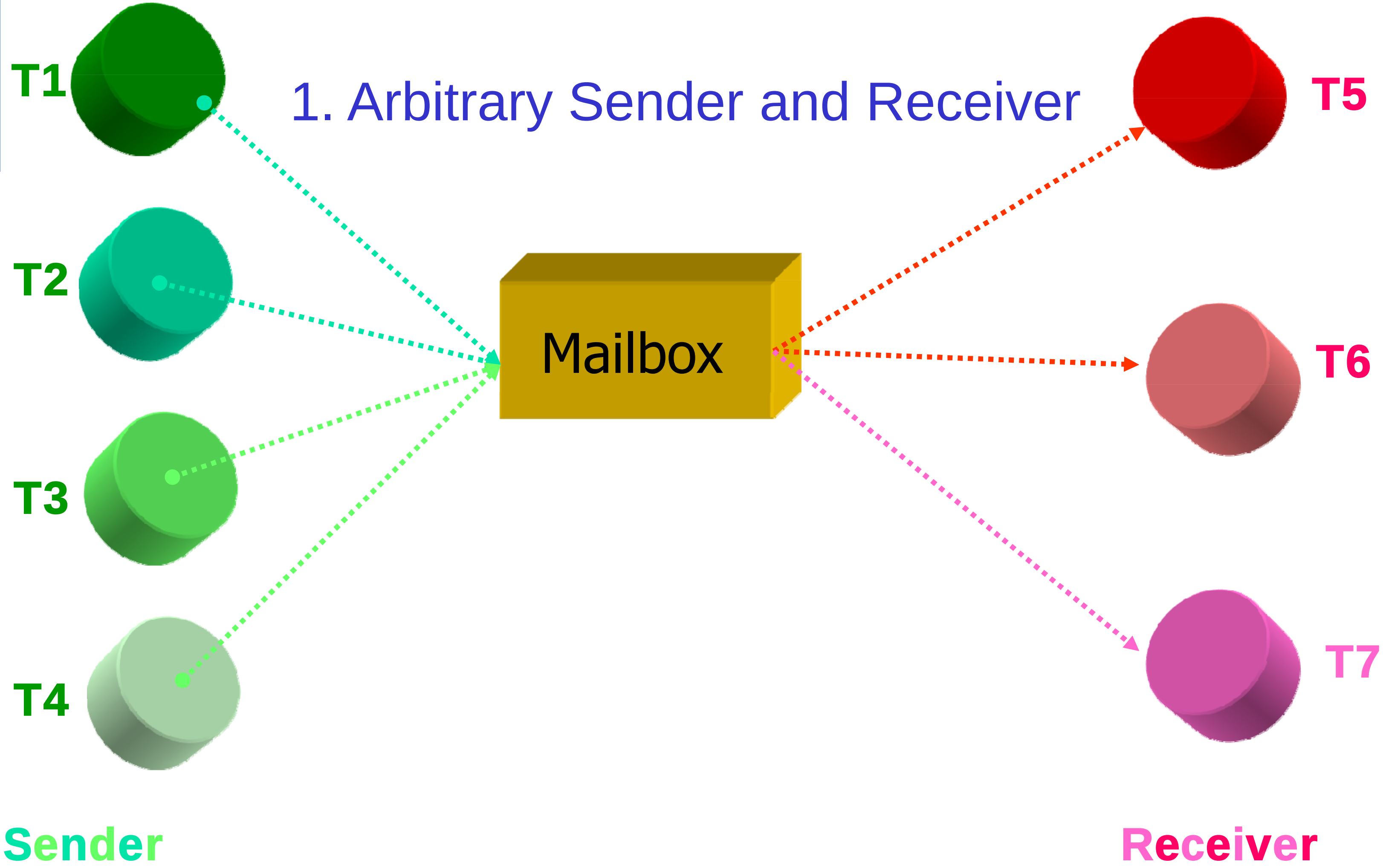
Different Semantics can be implemented:



- via mailbox, channel, port

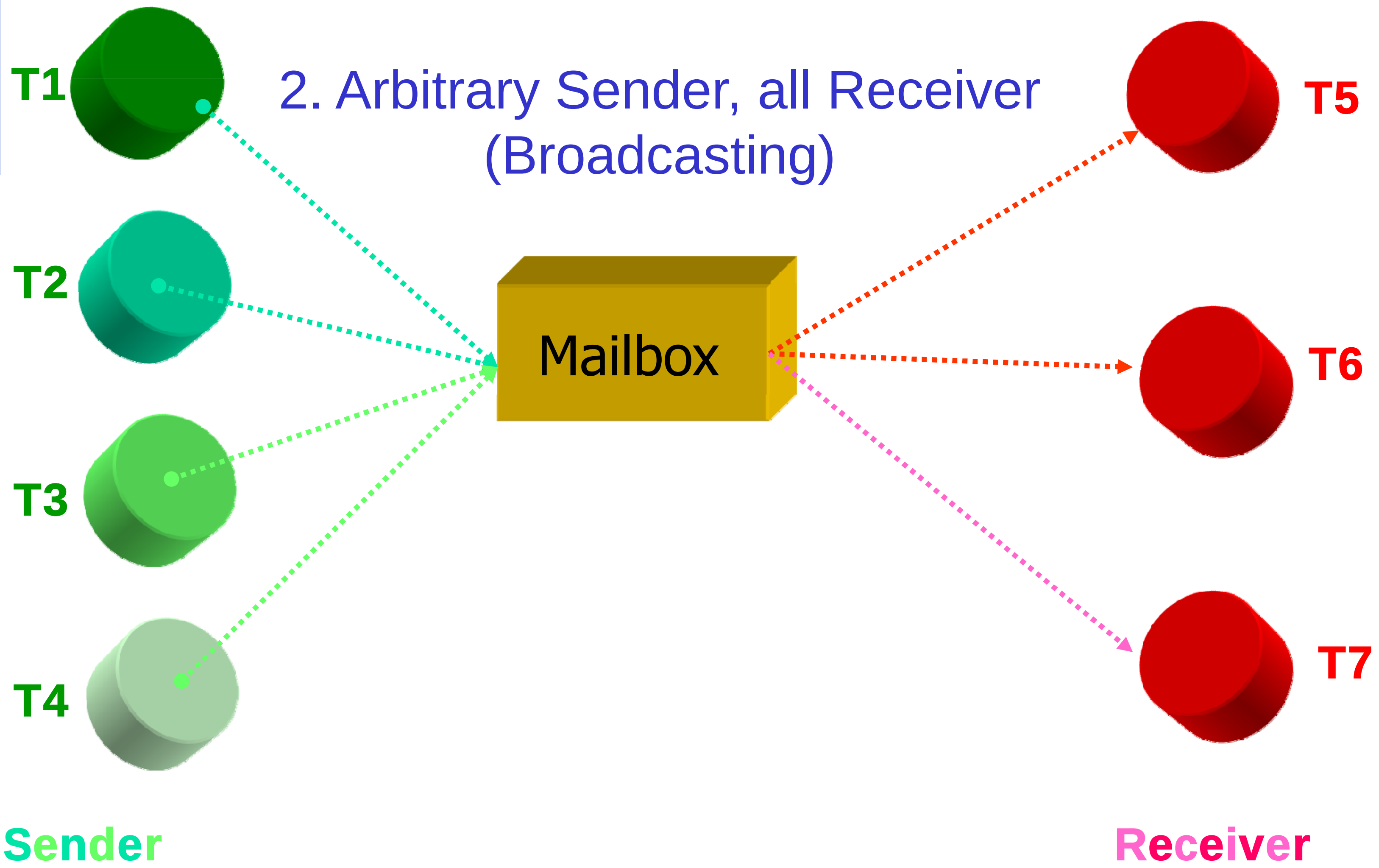
Indirect Communication (2)

1. Arbitrary Sender and Receiver



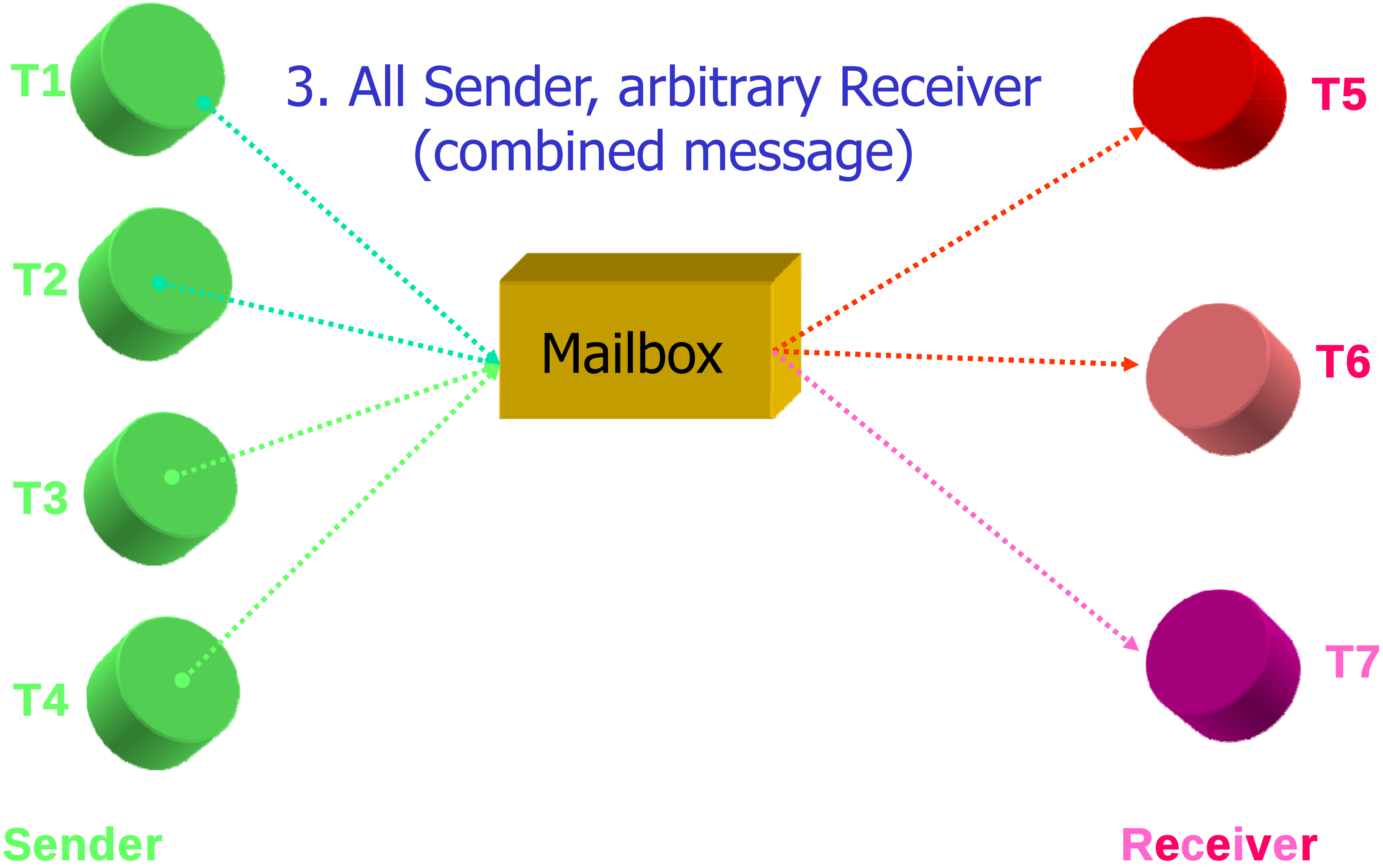
Indirect Communication

2. Arbitrary Sender, all Receiver
(Broadcasting)



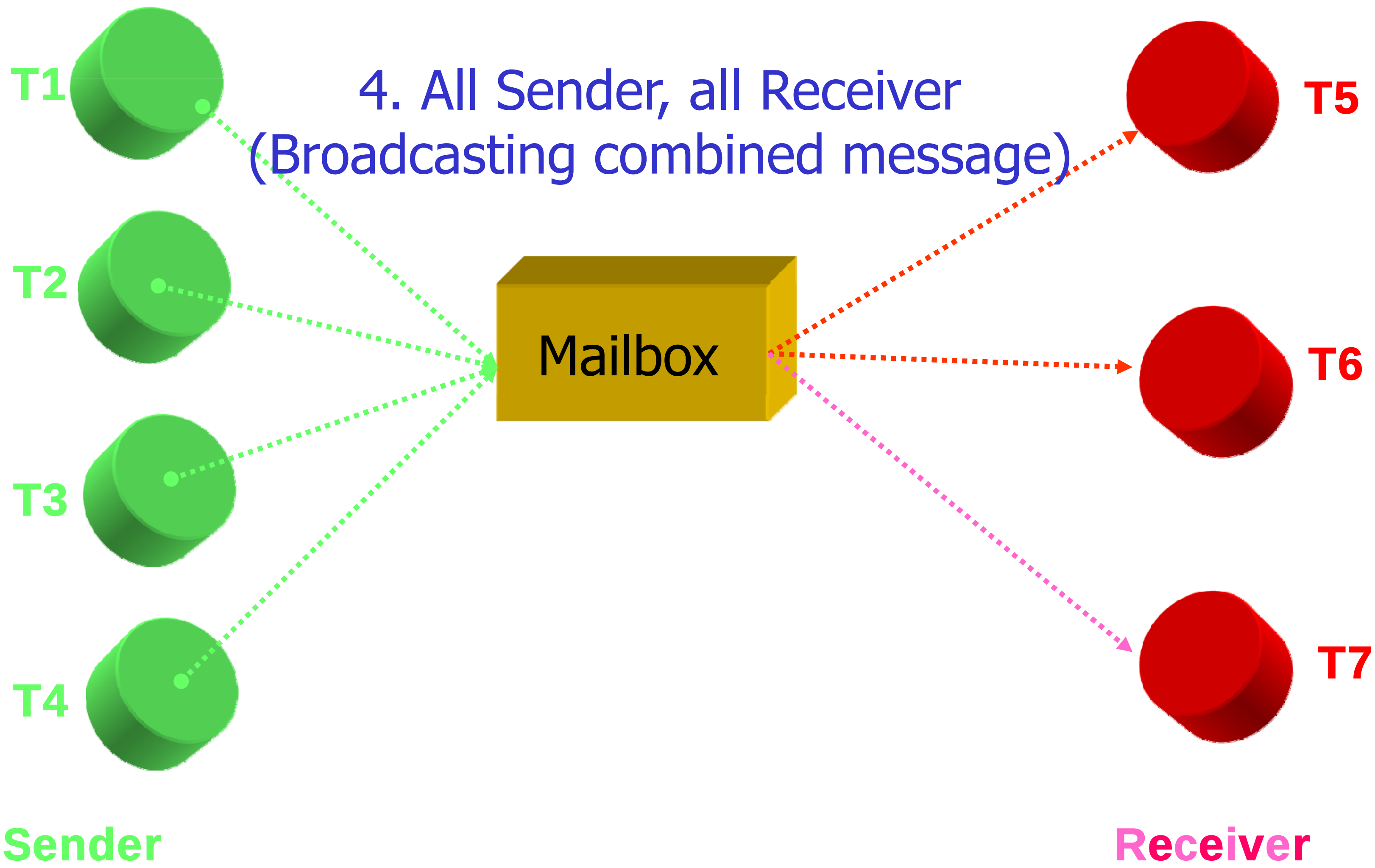
Indirect Communication

3. All Sender, arbitrary Receiver
(combined message)



Indirect Communication

4. All Sender, all Receiver
(Broadcasting combined message)



IPC Applications

Mutual Exclusion with RPC

Trick: Use a specific thread to execute the critical section!

```
Client Ti:
var msg: message;
repeat
  rpc(CSthread);
  RS
forever.
```

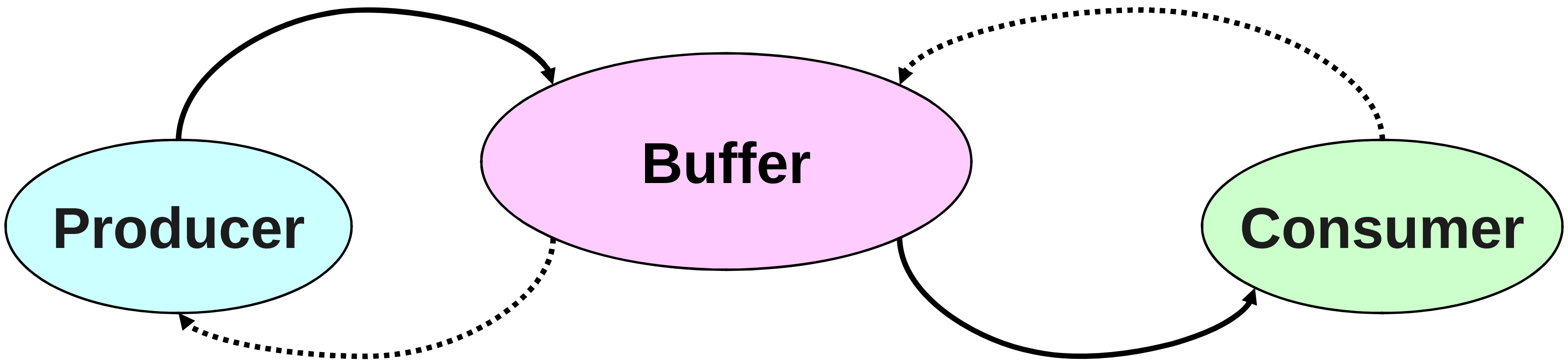
```
CSthread:
repeat
  client := receive(any);
  CS;
  send (client, "done")
forever.
```

Hint: Discuss the pros and cons of this solution

Producer/Consumer with RPC

```
Producer:
repeat
  rpc (Buffer, produce())
forever.
```

```
Consumer:
repeat
  msg = rpc(Buffer);
  consume(msg)
forever.
```



Producer/Consumer with RPC

```
Buffer:
state = normal:
repeat
  (client, msg) = receive(any);
  if (client == Producer)
    then put
  elif client = Consumer
    then get
  fi
forever.
```

```
get:
  if BufferNotEmpty()
    then msg := delete();
         send (client,msg);
         if state = ProducerPending
           then send (Producer,“ok”)
                state := normal;
           fi
    else state := ConsumerPending
  fi .
```

```
put:
  insert (msg) ;
  if BufferFull()
    then state := ProducerPending
    else send (client,“ok”);
         if state = ConsumerPending
           then send (Consumer, msg);
                dummy := delete();
                state := normal
         fi
  fi .
```

Mutex Emulation with IPC

create a mailbox *mutex*
shared by n threads

receive() blocks if *mutex* empty

send() is non blocking

Initialization: send(*mutex*, "go")

The first Ti executing receive() will enter its CS.

Others will be blocked until Ti sends back msg.

```
thread Ti:
var msg: message;
repeat
  receive(mutex,msg);
   CSi
   send(mutex,msg);
   RSi
forever
```

IPC Examples

Unix V IPC Mechanisms

To communicate data across tasks(processes):

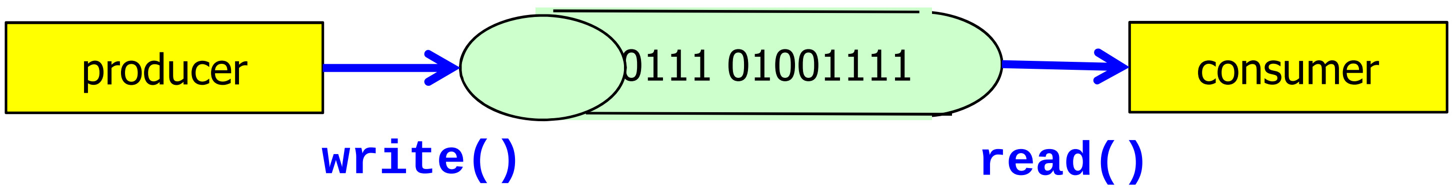
- Pipes
  - Anonymous pipe
  - Named pipe
- Messages
- Shared memory

To trigger actions by other tasks(processes):

- Signals
- Semaphores

Pipes

- Two processes can transfer a byte stream in FCFS order
- Pipes are "kernel objects" of size 4KB or 64 KB (cyclic buffer) depending on the Linux Version
- Pipes can be used at the
  - kernel API within application programs
  - user interface level via the "|" pipe operator
- Implicit synchronization is done in case of a full respectively empty pipe, i.e. the producer will automatically stop writing to the pipe, when the pipe has become full
- Writing into a pipe without any reader raises an exception



Anonymous Pipes

- Can only be used by processes of the same family (e.g. parent and child)
- Typically they are used only in a uni-directional way

Example Pipe

Pipe operator at CLI:

$ `more test.txt | lpr -kycera`

The content of file **`test.txt`** is sent via a pipe to the printer that will print out using printer kycera

$ `set | grep PATH`

The output of the **`set`** command will act as the input of the command **`grep`**. In this case all lines of the environment containing the character string **`PATH`** will be printed to standard output

Example Pipe at Kernel API (1)

```
main(){
   char buffer[5]; // buffer for received data
   int pp[2];      // descriptor for write end
                   // versus read-end of the pipe
   pipe(pp);       // create a new pipe pp
   if (fork()==0) {// child process as writer
     close(pp[0]); // close the read end of pp
     write(pp[1], „TEST“, 5); // write to pp
     …
     exit(0);      // end of child process
   }
```

Example Pipe Kernel API (2)

```
    // now within the parent process
    // acting as the reader
close(pp[1]);   // close write end of pp

read(pp[0], buffer, 5);
 printf(„ having read an item from pp: %s\n,
buffer);
…
}
```

<u>Remark:</u>
The close system calls are not necessary, but very helpful to prevent a consumer from writing to the pipe and vice versa

Named Pipes

- Can be used by non related process and in a bidirectional way (full duplex)
- Usual pipes are not persistent, i.e. they are deleted as soon as the last reader or writer is terminating
- A named pipe is an object of the file system and remains persistent, however its content is lost whenever the last writer terminates and there is no reader
- It can be reused in the future by any process that is authorized to access this named pipe

Example Named Pipe

For example, one can create a pipe **my_npipe** and set up gzip to compress things piped to it:

```
$ mkfifo my_npipe
$ gzip -9 –c < my_npipe > out.gz
$ rm rm my_npipe
```

In a separate process shell, independently, one could send the data to be compressed:

```
$ cat file > my_npipe
```

- Name pipes are often used to establish client-server relations

See: **http://developers.sun.com/solaris/articles/named_pipes.html**

Named Pipe at Kernel API

`int mkinfo(const char *path, mode_t mode)`

The system call function thakes the **`pathname`** to establish at the related directory a „pipe file object" with all the access rights that can be defined according to **`mode_t`**

A named pipe is used as a usual file, i.e. after having opende you can read or write to the named pipe.

Every write and read to a named pipe is atomic

Overview: System V IPC Resource

- Processes request IPC Resources that will
  - be created dynamically
  - be persistent
  - be used by any process (who knows the key)
  - have a 32-bit IPC key that can be selected by the programmer
  - be identified unambiguously by a 32-bit IPC identifier determined by the kernel

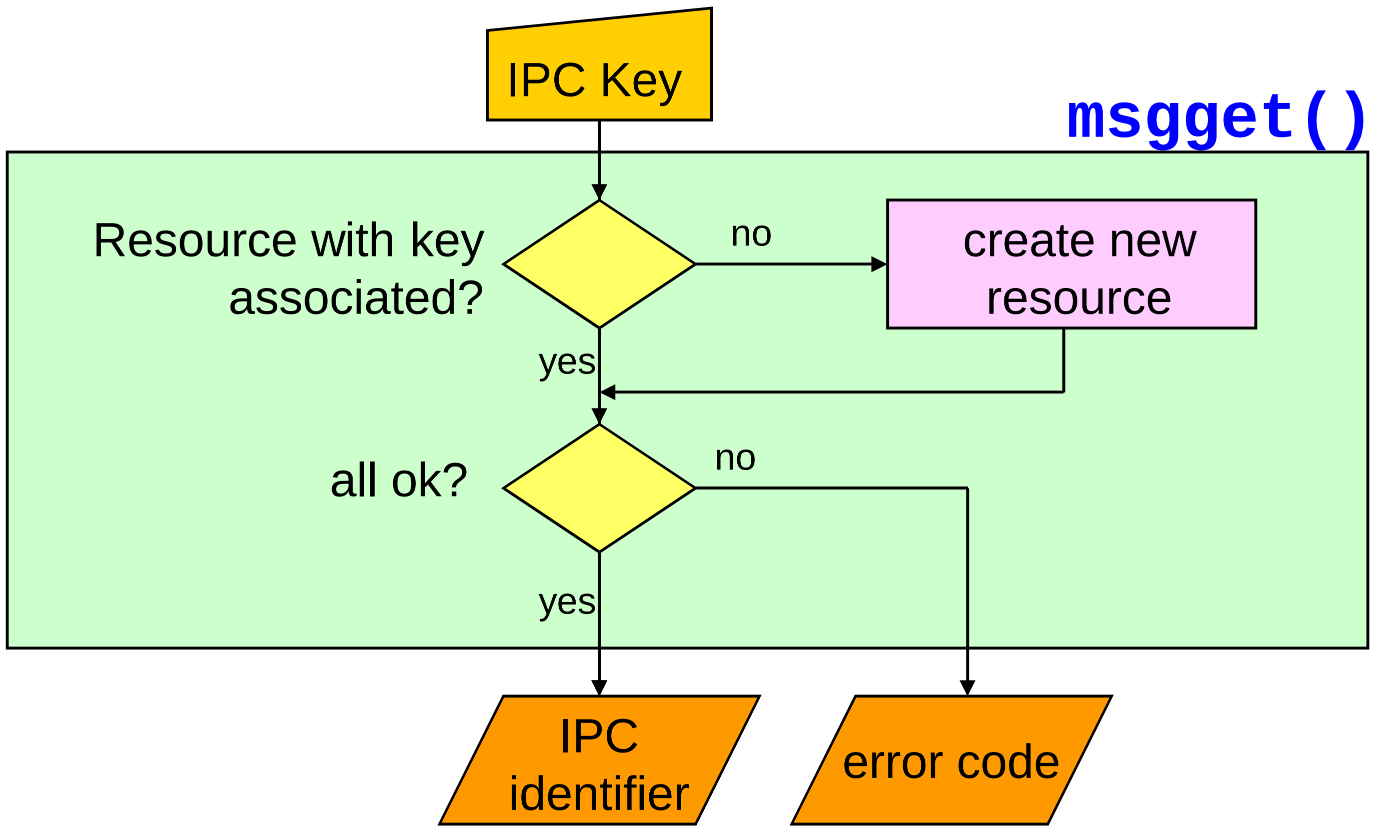
Semantics IPC

- IPC messages are sent asynchronously
- No FCFS order within a message queue
- IPC messages are deleted, once they have been received, i.e. only one process can read a message

Send & Receive

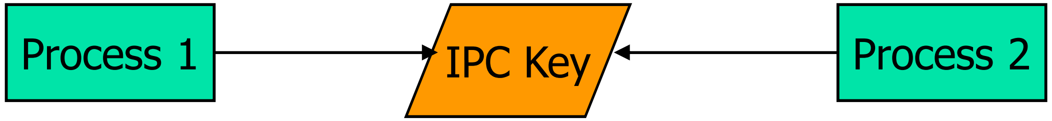
- `msgsnd()`
  - IPC identifier of the target message queue
  - Size of message
  - Address of a user mode buffer
- `msgrcv()`
  - IPC indentifier of the source queue
  - Pointer to a user mode buffer as the target
  - Size of buffer
  - Type t determines the message type, the caller is interested in

MSGGET

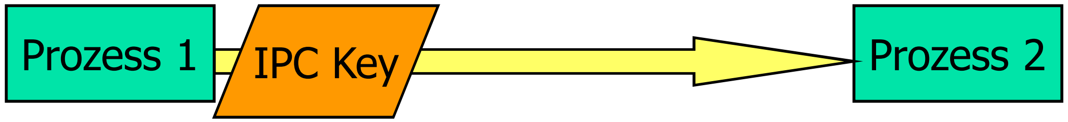

IPC Key
msgget()
Resource with key associated?
no
create new resource
yes
all ok?
no
yes
IPC identifier
error code

How to share a Message Queue?

1. Fixed, predefined IPC key
   - Simple case, works also for complicated applications
   - IPC key might be used by any process



2. Set IPC key = IPC_PRIVATE
   - IPC resource can not be used by another process
   - IPC identfier has to be sent to another process before it can use the IPC resource



System V IPC

- Kernel manages a message queue
- Sender processes can send messages to it
- Receiver processes can receive messages from it

```
int msgget(key_t key, int msgflag)
```

`key` is used to identify unambiguously the related message queue

The return value is either -1 in case of n error, or the message queue id

`msgflag` is used to specify what to do in case the message queue already exists

MSGflags

- **`IPC_CREAT`**

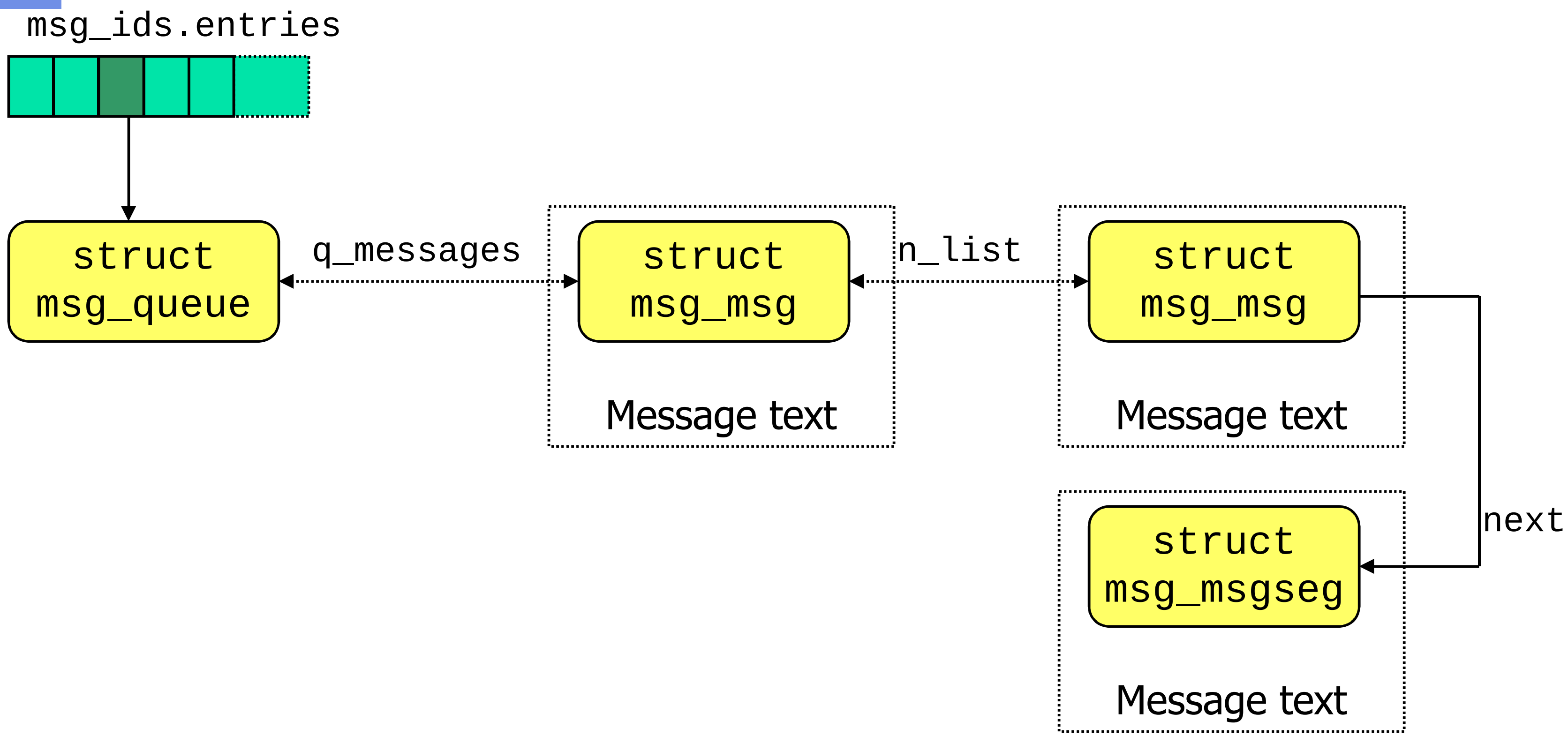
  resource **`msgqueue`** must be created, if not yet done

  if not set msgget simply returns the msg identifier

- **`IPC_EXCL`**

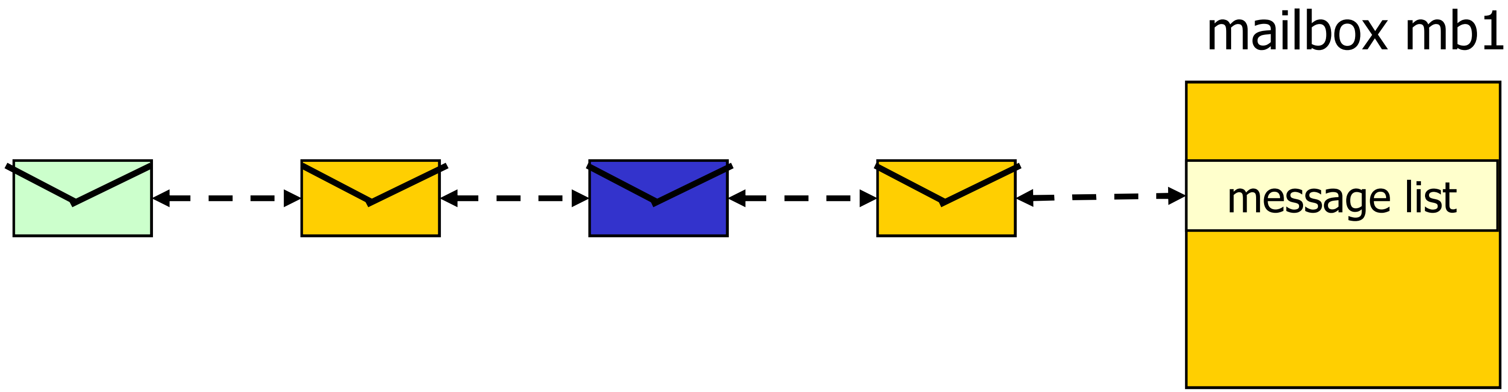
  `typeget()` schlägt fehl, wenn die Resource bereits existiert und **`IPC_CREAT`** gesetzt ist.

Implementing Message Queues



Unix Typed Messages

- In **`receive()`** receiver specifies that it is only interested in a message of specific type
- The message type is either defined in the message at a specific location or it is a parameter of **`send()`**



Example: **`receive(mb1, blue_letter)`**

IPC of L4*

Characteristics of L4 IPCs:

- Synchronous
- Direct addressing
  - **`send(tid, message)`**
  - **`receive(tid, message)`**
  - **`receive(from any, message)`**
  - **`call(tid, request)`**
  - **`reply&wait(tid, answer)`**

*see http://www.l4ka.org/projects/pistachio/