TECHNISCHE UNIVERSITÄT
KAISERSLAUTERN

Programming Distributed Systems

Introduction to Erlang

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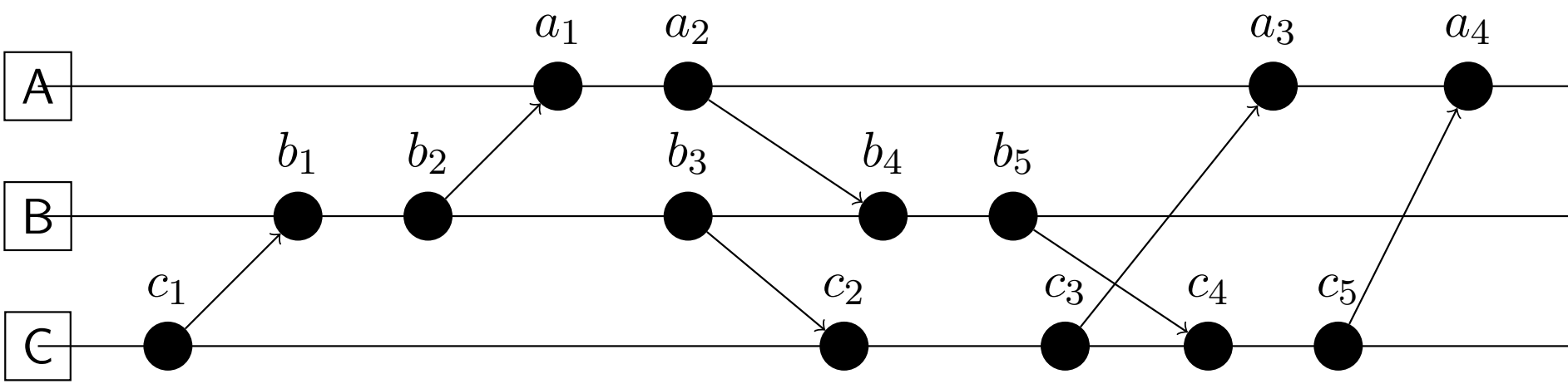
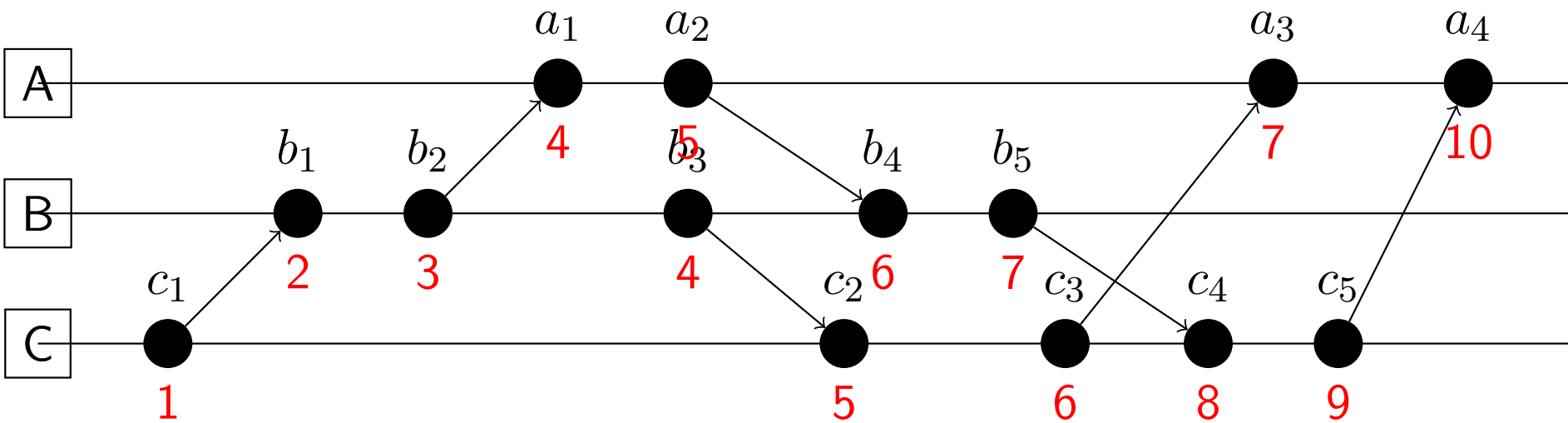
Logical Clocks



Logical Clocks



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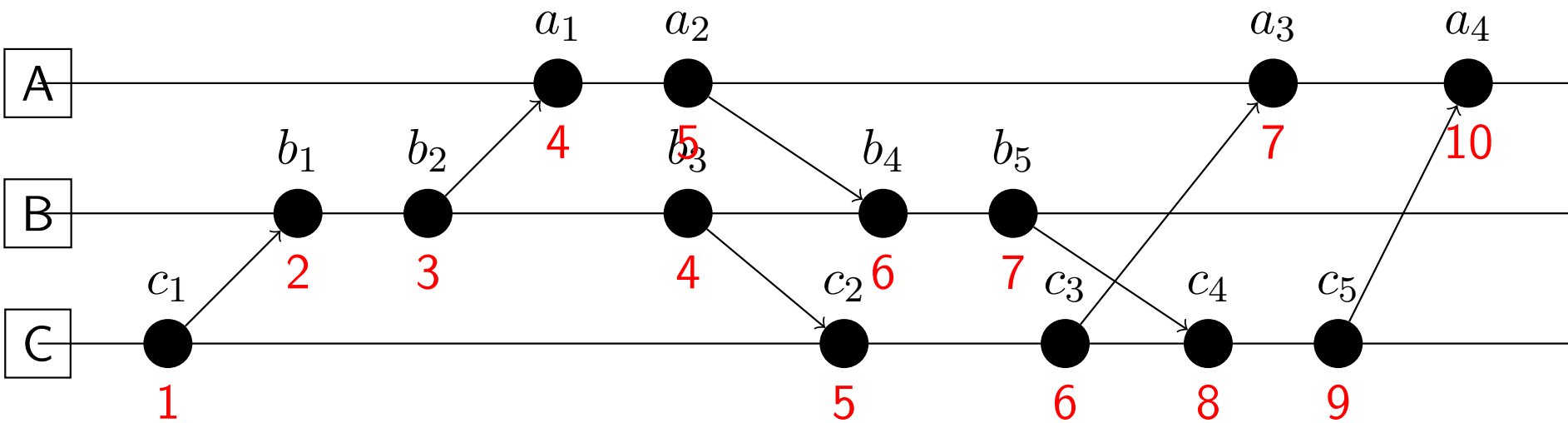
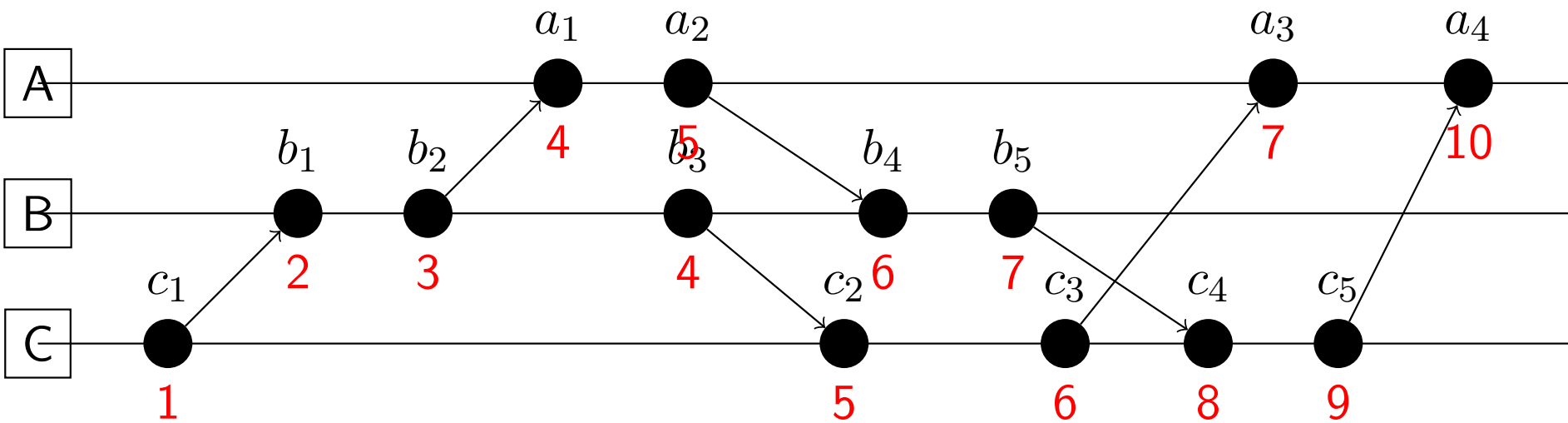


Give an example execution that shows: $t(e_1) < t(e_2)$ does not imply that $e_1 \rightarrow e_2$.

Logical Clocks



Give an example execution that shows: $t(e_1) < t(e_2)$ does not imply that $e_1 \rightarrow e_2$.

b5 and c3

3c)

Assume $e_1 \rightarrow e_2$ and show $t(e_1) < t(e_2)$. Proof by induction over the inductive definition of the happens before-relation:

Case 1: If e_1 and e_2 are events in the same process and e_1 comes before e_2:
Since l_p is strongly monotonically increasing for each event, we have $t(e_1) < t(e_2)$.

Case 2: If e_1 is the sending of a message by one process and e_2 is the receipt of the same message by another process:
Then the message must include $t(e_1)$. As $t(e_2) = max(t(e_1), l_p) + 1$, we have $t(e_2) > t(e_1)$.

Case 3: Transitivity: There is an event e', such that $e_1 \rightarrow e'$ and $e' \rightarrow e_2$. By induction hypothesis, we have $t(e_1) < t(e')$ and $t(e') < t(e_2)$ and because $<$ is transitive on natural numbers, we get $t(e_1) < t(e_2)$.

1a)

Write a function `maximum/2`, which takes two numbers and returns the maximum of the two. Do not use the built-in `max` function. Hint: You can use the **`if`**-expression, **`case`**-expression or guards.

```
maximum(X, Y) when X > Y -> X;
maximum(_, Y) -> Y.
```

1a)

Write a function `maximum/2`, which takes two numbers and returns the maximum of the two. Do not use the built-in `max` function. Hint: You can use the **`if`**-expression, **`case`**-expression or guards.

```
maximum(X, Y) when X > Y -> X;
maximum(_, Y) -> Y.

maximum2(X, Y) ->
    case X > Y of
        true -> X;
        false -> Y
    end.

maximum3(X,Y) ->
    if
        X > Y -> X;
        true -> Y
    end.
```

1b)

Write a function `list_max/1`, which takes a nonempty list of numbers and computes the maximal element in the list. Do not use the built-in function `lists:max`. Use recursion to implement the function.

```
list_max([X]) -> X;
list_max([X|Xs]) -> maximum(X, list_max(Xs)).
```

1b)

Write a function `list_max/1`, which takes a nonempty list of numbers and computes the maximal element in the list. Do not use the built-in function `lists:max`. Use recursion to implement the function.

```
list_max([X]) -> X;
list_max([X|Xs]) -> maximum(X, list_max(Xs)).

% tail-recursive-variant
list_max_tailrec([X|Xs]) -> list_max_h(Xs, X).

list_max_h([], Max) -> Max;
list_max_h([X|Xs], Max) -> list_max_h(Xs, maximum(X, Max)).
```

1c)

Write a function `sorted/1`, which takes a list of numbers and checks, whether it is sorted in ascending order.

```
sorted([]) -> true;
sorted([_]) -> true;
sorted([X,Y|Rest]) -> X =< Y andalso sorted([Y|Rest]).
```

1d)

Write a function `swap/1`, which takes a pair and returns a pair where the two components are swapped.

```
swap({X, Y}) -> {Y,X}.
```

1e)

Write a function `find/2`, which takes a key and a list of key-value pairs. The function should return `{ok, X}`, if `X` is the value of the first pair in the list that has the given key. If no entry with the given key exists, the function should return **`error`**.

```
find(_, []) -> error;
find(Key, [{Key,Val}|_]) -> {ok, Val};
find(Key, [_| Rest]) -> find(Key, Rest).
```

1f)

Write a function `find_all/2`, which takes a list of keys and a list of key-value pairs. The function should use the `find`-function above to lookup every key from the first in the second list. The result should be a list of all key-value pairs that were found with the same order as they appeared in the given list of keys.

```
find_all([], _) -> [];
find_all([Key|Keys], Dict) ->
    case find(Key, Dict) of
        {ok, Val} -> [{Key, Val}|find_all(Keys, Dict)];
        error -> find_all(Keys, Dict)
    end.
```

g)

Use `lists:filter/2` to write a function `positive/1`, which takes a list of numbers `L` and returns a list of all numbers in `L`, which are greater or equal to 0.

```
positive(L) ->
    lists:filter(fun(X) -> X >= 0 end, L).
```

h)

Use `lists:all/2` to write a function `all_positive/1`, which takes a list of numbers and checks whether all numbers in the list are greater or equal to 0.

```
all_positive(L) ->
    lists:all(fun(X) -> X >= 0 end, L).
```

i)

Use `lists:map/2` to write a function `values/1`, which takes a list of key-value pairs and returns a list of only the values.

```
values(L) ->
    lists:map(fun({_, X}) -> X end, L).
```

j)

Use `lists:foldl/3` to write a function `list_min`, which computes the minimal element of a nonempty list.

```
minimum(X, Y) when X < Y -> X;
minimum(_, Y) -> Y.

list_min([X|Xs]) ->
lists:foldl(fun minimum/2, X, Xs).
```

List comprehensions

```
> L1 = [1,14,7,6].
> L2 = [a, {ok, 3}, {ok, 4}, b].
[2*X || X <- L1].
% [2,28,14,12]

[2*X || {ok, X} <- L2].
% [6,8]

[{ok, 2*X} || X <- L1, X < 10].
% [{ok,2},{ok,14},{ok,12}]

[{X,Y} || X <- L1, Y <- [a,b]].
% [{1,a},{1,b},{14,a},{14,b},{7,a},{7,b},{6,a},{6,b}]
```

In General: `[Expression || Qualifier1, Qualifier2, ...]`

- Generator Qualifier: `Pattern <- ListExpr`
- Filter Qualifier: Boolean expression

Concurrent programming

Processes

Creating a new process:

```
spawn_link(Fun)
spawn_link(Module, Function, Args)
```

Example:

```
F = fun() ->
    timer:sleep(5000), % sleep 5 seconds
    io:format("Hello from process ~p!~n", [self()])
  end.
Pid = spawn_link(F).
```

Messages

Sending messages:

```
Receiver ! Message
```

Receiving messages:

```
receive
    Pattern1 -> Expr1;
    Pattern2 -> Expr2;
    ...
    PatternN -> ExprN
end
```

- takes first message from mailbox that matches one of the patterns
- blocks until matching message available
- FIFO order (messages from same origin are ordered)

Message example 1

```
Pid = spawn_link(fun() ->
    receive
        a -> io:format("Received a~n")
    end,
    receive
        a -> io:format("Received a~n");
        b -> io:format("Received b~n")
    end
  end).
Pid ! b.
Pid ! a.
```

Message example 2

```
Pid = spawn_link(fun() ->
    timer:sleep(10000),
    receive
        a -> io:format("Received a~n");
        b -> io:format("Received b~n")
    end
  end).
Pid ! b.
Pid ! a.
```

Timeouts

Receive with timeouts:

```
receive
    Msg -> ...
after 5000 -> % timeout after 5000ms
    ...
end
```

Use timeout 0 to check if message is already in mailbox without blocking.

Example: Echo server 1

```
-module(echo).
-export([start_link/0]).

start_link() ->
    {ok, spawn_link(?MODULE, loop, [])}.

loop() ->
    receive
        {From, Msg} ->
            From ! Msg,
            loop();
        stop ->
            true
    end.
```

Example: Echo server 1

```
-module(echo).
-export([start_link/0]).

start_link() ->
    {ok, spawn_link(?MODULE, loop, [])}.

loop() ->
    receive
        {From, Msg} ->
            From ! Msg,
            loop();
        stop ->
            true
    end.
```

Problem: What if receiver also gets other messages?

Example: Echo server 2

```
-module(echo).
-export([start_link/0]).

start_link() ->
    {ok, spawn_link(?MODULE, loop, [])}.

loop() ->
    receive
        {From, Msg} ->
            From ! {self(), Msg},
            loop();
        stop ->
            true
    end.
```

Sending own process-id (`self()`), so that receiver can match answer to request.

Example: Counting server

```
-module(counter).
-export([start_link/0]).

start_link() ->
    {ok, spawn_link(?MODULE, loop, [0])}.

loop(Counter) ->
    receive
        {From, increment} ->
            From ! {self(), ok},
            loop(Counter + 1);
        {From, read} ->
            From ! {self(), Counter},
            loop(Counter)
        stop ->
            true
    end.
```

Records: Organizing complex state in a server

```
-record(person, {name, age, hobbies = []}).
```

Creating instances:

```
P = #person{name = "Hans", age = 7}.
```

Accessing fields:

```
P#person.name.
P#person.age.
```

Updating record fields:

```
P#person{age = 8}.
```

Pattern matching with records:

```
#person{name = Name, age = Age} = P.
```

```
-record(state, {limit, count}).

start_link(Limit) ->
    State = #state{limit = Limit, count = 0},
    {ok, spawn_link(?MODULE, loop, [State])}.

loop(State = #state{counter = Counter, limit = Limit}) ->
    receive
        {From, increment} when Counter < Limit ->
            From ! {self(), ok},
            loop(State#state{counter = Counter + 1});
        {From, increment} ->
            From ! {self(), {error, limit_reached}},
            loop(State);
        {From, read} ->
            From ! {self(), Counter},
            loop(State);
        stop ->
            true
    end.
```