Lesson 9

# Concurrency Control in Distributed Environment

*Ch 8 [BenA 06]*

Messages
Channels
Rendezvous
RPC and RMI

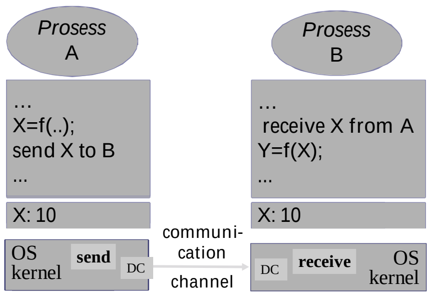


## Distributed System

- No shared memory
- Communication with messages
- Tighly coupled systems
  - Processes alive at the same time
- Persistent systems
  - Data stays even if processes die
- Fully distributed systems
  - Everything goes



## Communication with Messages (4)




- Sender, receiver
- Synchronous/asynchronous communication

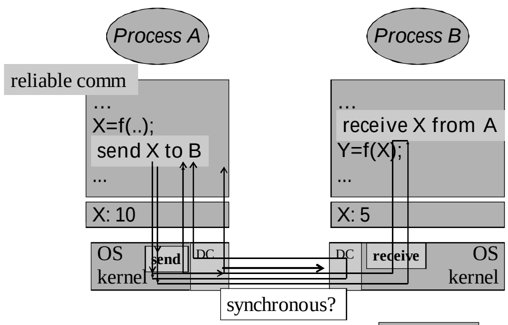


## Message Passing

- Synchronous communication
  - Atomic action
  - Both wait until communication complete
- Asynchronous communication — Usual case
  - Sender continues after giving the message to OS for delivery
  - May get an acknowledgement later on
    - Message received or not
- Addressing
  - Some address for receiver process — prosessi
    - Process name, id, node/name, …
  - Some address for the communication channel — kanava
    - Port number, channel name, …
  - Some address for requested service — palvelu
    - Broker will find out, sooner or later — meklari
      - After message has been sent?
    - Service address not known at service request time

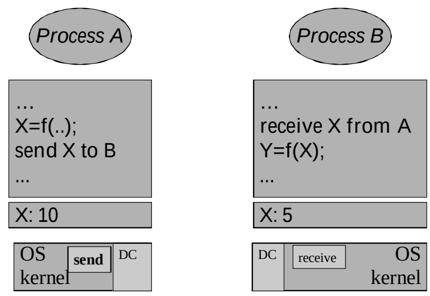


## Synchronization levels (10)

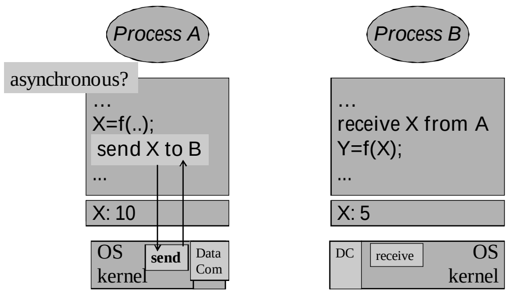





## Synchronization levels (1/5)

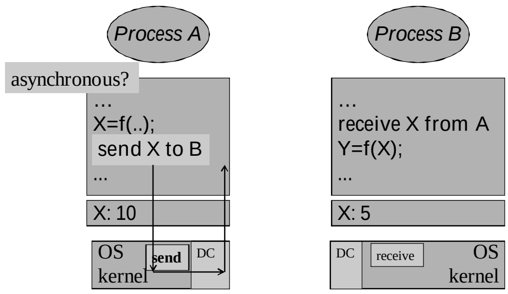


## Synchronization levels (2/5)



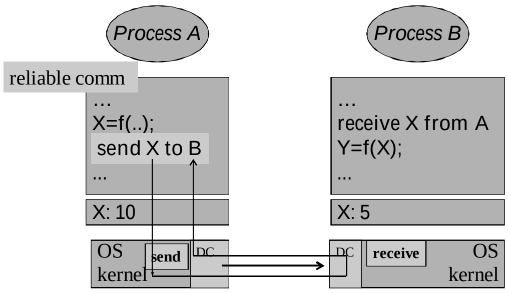



## Synchronization levels (3/5)



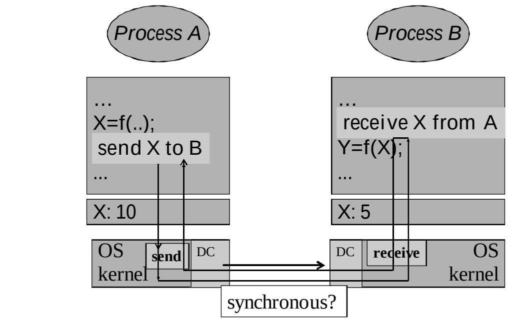



## Synchronization levels (4/5)






## Synchronization levels (5/5)






## Message Passing

- Symmetric communication
  - Cooperating processes at same level
  - Both know about each others address
  - Communication method for a fixed channel
- Asymmetric communication
  - Different status for communicating processes
  - Client-server model
    - Server address known, client address given in request
- Broadcast communication
  - Receiver not addressed directly
  - Message sent to everybody (in one node?)
  - Receivers may be limited in number
    - Just one?
    - Only the intended recipient will act on it?



## Wait Semantics

- Sender
  - Continue after OS has taken the message — Usual case
    - Non-blocking send
  - Continue after message reached receiver <u>node</u>
    - Blocking send
  - Continue after message reached receiver <u>process</u>
    - Blocking send
- Receiver
  - Continue only after message received — Usual case
    - Blocking receive
  - Continue even if no message received
    - Status indicated whether message received or not
    - Non-blocking receive

# Message Passing

- Data flow
  - One-way
    - Synchronous may be one-way
    - Asynchronous is always one-way
  - Two-way
    - Synchronous may be two-way
    - Two asynchronous communications
- Primitives
  - One message at a time
  - Need addresses for communicating processes
  - Operating system level service
  - Usually not programming language level construct
    - Too primitive: need to know node id, process id, port number,…

data flow vs. control flow!





# Channels

- History of languages utilizing channels
  - Guarded Commands
    - Dijkstra, 1975
  - Communicating Sequential Processes
    - CSP, Hoare, 1978
  - Occam
    - David May et al, 1983
    - Hoare as consultant
    - Inmos Transputer


Edsger Dijkstra


C.A.R. Hoare


David May



# Guarded Commands (Dijkstra)

- Way to describe predicate transformer semantics
- Communication not really specified
- Guarded command
  - Condition or guard
  - Statement

predikaatti-muunnos-semantiikka

C → S

greatest common divisor

```
x, y = X, Y     -- statement (unguarded)
do   -- loop command, loop terminates when x = y
  x ≠ y →
     if     -- conditional command (itself guarded)
        x > y → x := x-y     -- guarded statement in the if
        y > x → y := y-x
     fi
od
print x ; -- another statement, also unguarded
```

guard

vartioitu lauseke

can be also input/output statement

http://en.wikipedia.org



# Communicating Sequential Processes – CSP (Hoare)

- Language for modeling and analyzing the behavior of concurrent communicating systems
- A known group of processes A, B, …
- Communication:
  - output statement: B!e
    - evaluate e, send the value to B
  - input statement: A?x
    - receive the value from A to x
  - input, output: blocking statements
  - output & input: "distributed assignment"
    - Communicate value from one process to a variable in some other process

A: B!e

e

B: A?x

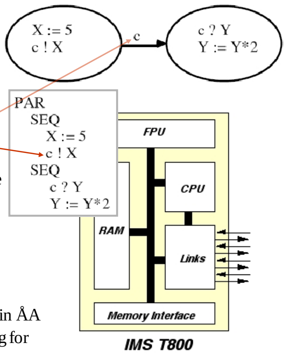


# CSP communication

- Input/output statements
  - Destination!port ($e_1$, …, $e_n$) ;
  - Source?port ($x_1$, …, $x_n$) ;
- Binding
  - Communication with **named processes**
  - Matching types for communication
- Example: **Copy** ( West => Copy => East )

| West: | Copy: | East: |
|---|---|---|
| **do** true -> Copy!c; … **od** | do true -> West?c; East!c ; od | do true -> Copy?c; … od |

## OCCAM Language

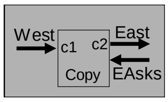



- Communication through **named channels**
  - Globally defined
    - Somewhere, in advance
  - Each channel has one sender and one receiver
    - Process in some node
- Transputer
  - Multicomputer
    - E.g., 100 node Hathi-2 in ÅA
  - Automatic message routing for channels
  - Programmed with OCCAM

http://www.embedded.com.au/reference/transputers.html



## OCCAM Example (Andrews, p 331)




```
PROC Copy (CHAN OF BYTE West, EAsks, East)
  BYTE c1, c2, dummy;  -- buffer size = 2
  SEQ
    West ? c1                 -- West has 1st byte
    WHILE TRUE
      ALT
        West ? c2             -- West has new byte
          SEQ
            East ! c1         -- send previous byte
            c1 := c2          -- copy to buffer c1
        EAsks ? dummy         -- East wants a byte
          SEQ
            East ! c1         -- send previous byte
            West ? c1         -- receive next one
```

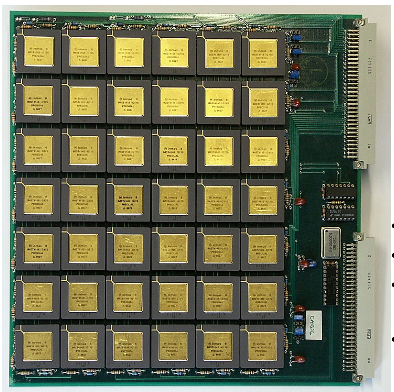
block here, until other end ready ("guards")

- How to bind processes to nodes? 8 vs. 100 nodes?
- How to bind channels to processes, physical system?
  - 4 physical ports (N, S, E, W) in each processor

Discussion 2



## Inmos Transputer



- B0042
- 2D array
- 10 boards 420 cpu's
- 30 boards 1260 cpu's

http://www.cs.bris.ac.uk/~dave/transputer.html



## Channels

- Communication through named channels
  - Typed, global to processes
  - Programming language concept
  - Any one can read/write (usually limited in practice)
- Pipe or mailbox
- Synchronous, one-way (?)
- How to tie in with many nodes?
  - Not really thought through! Easy with shared memory!

many readers/writers? same process writes and reads?

**Algorithm 8.1: Producer-consumer (channels)**

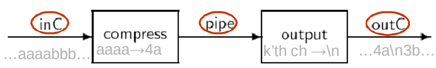
channel of integer ch

| producer | consumer |
|---|---|
| integer x | integer y |
| loop forever | loop forever |
| p1: x ← produce | q1: ch ⇒ y |
| p2: ch ⇐ x | q2: consume(y) |

buffer size?



## Filtering Problem




- Compress many (at most MAX) similar characters to pairs …
  - {nr of chars, char}
- … and place newline (\n) after every K'th character in the compressed string
- Why is it called "Conway's problem"?
  - "Classic coroutine example"

"compress"

"output"

vuorottaisrutiinit

**Conway, M. "Design of a separable transition-diagram compiler," *CACM* 6, 1963, pages 396–408.**



## Filtering Problem with Channels

**Algorithm 8.2: Conway's problem**

constant integer MAX ← 9
constant integer K ← 4
channel of integer inC, pipe, outC

| compress | output |
|---|---|
| char c, previous ← 0 | char c |
| integer n ← 0 | integer m ← 0 |
| inC ⇒ previous | |
| loop forever | loop forever |
| p1: inC ⇒ c | q1: pipe ⇒ c |
| p2: if (c = previous) and (n < MAX − 1) | q2: outC ⇐ c |
| p3: n ← n + 1 | q3: m ← m + 1 |
| else | |
| p4: if n > 0 | q4: if m >= K |
| p5: pipe ⇐ intToChar(n+1) | q5: outC ⇐ newline |
| p6: n ← 0 | q6: m ← 0 |
| p7: pipe ⇐ previous | q7: |
| p8: previous ← c | q8: |

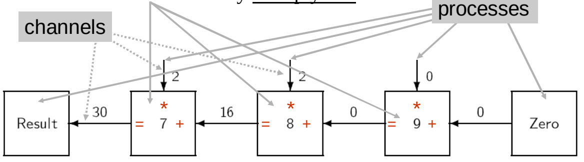
no last char?

## Matrix Multiplication with Channels

$$\begin{pmatrix}1&2&3\\4&5&6\\7&8&9\end{pmatrix} \times \begin{pmatrix}1&0&2\\0&1&2\\1&0&0\end{pmatrix} = \begin{pmatrix}4&2&6\\10&5&18\\16&8&30\end{pmatrix}$$

- 16 = (7 8 9) ● (1 0 1)
- 30 = (7 8 9) ● (2 2 0)
- Process for every multiply-add

7*2+ 8*2+ 9*0+ 0

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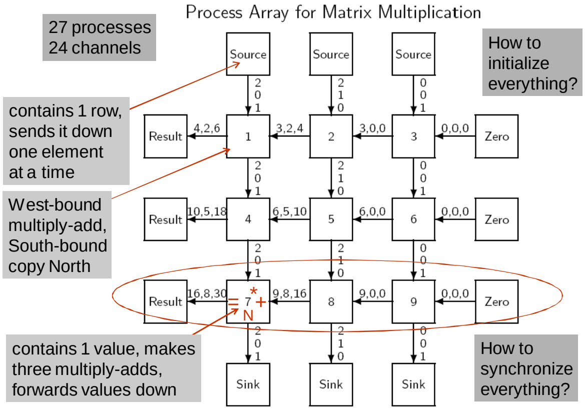
## Process Array for Matrix Multiplication

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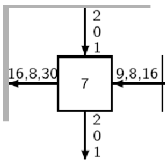
**Algorithm 8.3: Multiplier process with channels**

```
         integer FirstElement
         channel of integer North, East, South, West
         integer Sum, integer SecondElement
   loop forever
p1:   North ⇒ SecondElement          ← wait 1st for this (*)
p2:   East ⇒ Sum                     ← and then for this
p3:   Sum ← Sum + FirstElement · SecondElement
p4:   South ⇐ SecondElement
p5:   West ⇐ Sum
```

Relative names?




- How to map processes to nodes?
- How to map channels to processes?
  - North channel of one process the South channel of some other
- North-South data flow has priority (*)
  - Waiting even when data-flow East-West available
  - Node on East may be blocked unnecessarily

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**Algorithm 8.4: Multiplier with channels and selective input**

```
         integer FirstElement
         channel of integer North, East, South, West
         integer Sum, integer SecondElement
   loop forever
     either
p1:     North ⇒ SecondElement        If message from North
p2:     East ⇒ Sum                   available, do this
     or
p3:     East ⇒ Sum                   If message from East
p4:     North ⇒ SecondElement        available, do this
p5:   South ⇐ SecondElement          sequential block
p6:   Sum ← Sum + FirstElement · SecondElement
p7:   West ⇐ Sum
```

- Guarded statement
  - Execute one selective input statement
    - Nondeterministic selection (if both available)
    - p2 follows p1, it does not compete with p3

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## Dining Philosophers with Channels

- Each fork i is a process, forks[i] is a channel
- Each philosopher i is a process

**Algorithm 8.5: Dining philosophers with channels**

channel of boolean forks[5]

| philosopher i | fork i |
|---|---|
| boolean dummy | boolean dummy |
| loop forever | loop forever |
| p1: think | q1: forks[i] ⇐ true |
| p2: forks[i] ⇒ dummy | q2: forks[i] ⇒ dummy |
| p3: forks[i⊕1] ⇒ dummy | q3: |
| p4: eat | q4: mutex? |
| p5: forks[i] ⇐ true (would *false* be ok?) | q5: deadlock? |
| p6: forks[i⊕1] ⇐ true | q6: |

- Would it be enough to initialize each *forks[i] <= true* ?
  - Do you really need *forks[i] => dummy* in fork i? Why?

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# Rendezvous (1978, Abrial & Andrews)

- Synchronization with communication
  - No channels, usage similar to procedure calls
  - One (*accepting*) process waits for one of the (*calling*) processes
    - One request in service at a time
  - Calling process must know id of the accepting process
  - Accepting process does not need to know the id of calling process
  - May involve parameters and return value
- Good for client-server synchronization
  - Clients are calling processes `server.service(parm, result)`
  - Server is accepting process `accept service(p, r)`
  - Server is active process
  - Language construct, no mapping for real system nodes

asymmetric



**Algorithm 8.6: Rendezvous**

| client | | server | |
|---|---|---|---|
| | integer parm, result | | integer p, r |
| | loop forever | | loop forever |
| p1: | parm ← . . . | q1: | |
| p2: | server.service(parm, result) | q2: | accept service(p, r) |
| p3: | use(result) | q3: | r ← do the service(p) |

- Can have many similar clients
- Implementation with messages (e.g.)
  - Service request in one message
    - Arguments must be marshalled (make them suitable for transmission)
  - Wait until reply received
  - Reply result in another message



# Guards in Rendezvous

- Additional constraint for accepting given service call
- Accept service call, if
  - Someone requests it and
  - Guard for that request type is true
    - Guard is based on local state
- If many such requests (with open guards) available, select one randomly
- Complete one request at a time
  - Implicit mutex



# Ada Rendezvous

Bounded Buffer in Ada

Export public ops defined before task body

```
task body Buffer is
  B: Buffer_Array;
  In_Ptr, Out_Ptr, Count: Index := 0;
begin
  loop
    select
      when Count < Index'Last =>
        accept Append(I: in Integer ) do
          B(In_Ptr) := I;
        end Append;
      Count := Count - 1; In_Ptr := In_Ptr + 1;
    or
      when Count > 0 =>
        accept Take(I: out Integer ) do
          I := B(Out_Ptr);
        end Take;
      Count := Count - 1; Out_Ptr := Out_Ptr - 1;
    or
      terminate;
    end select;
  end loop;
end Buffer;
```

…
Buffer.Append (456);
Buffer.Append (333);
…

…
Buffer.Take(x);
Buffer.Take(y);
…

Terminates when no rendezvous processes available? Tricky! How to know? No concurrent operations!





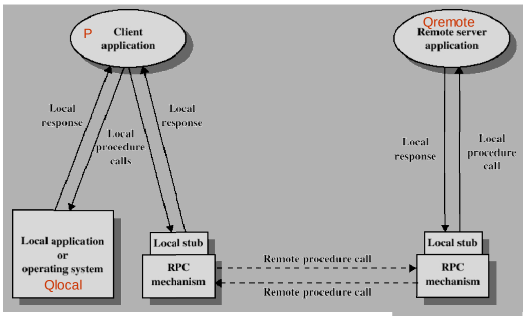
# Remote Procedure Call

- Common operating system service for client-server model synchronization
  - Implemented with messages
  - Parameter marshalling
    - Semantics remain, implementation may change
  - Mutex problem
    - Combines monitor and synchronized messages?
      - Automatic mutex for service
    - Multiple calls active simultaneously?
      - Mutex problems solved within called service
  - Semantics similar to ordinary procedure call
    - But no global environment (e.g., shared array)
  - Two-way synchronized communication channel
    - Client waits until service completed (usually)

Usual case

## RPC System Structure

P calls Q




(Sta05 Fig 14.12)

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## RPC Module

```
module mname
  op opname(formals) [returns result]     Export public ops
body
  variable declarations;
  initialization code;
  proc opname(formal identifiers) returns result identifier
    declarations of local variables;
    statements
  end
  local procedures and processes;
end mname
```

Call: `call mname.opname(arguments)`

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## RPC Example: Time Server

```
module TimeServer
  op get_time() returns int;     # retrieve time of day
  op delay(int interval);        # delay interval ticks
body
  int tod = 0;                   # the time of day
  sem m = 1;                     # mutual exclusion semaphore
  sem d[n] = ([n] 0);            # private delay semaphores
  queue of (int waketime, int process_id) napQ;
  ## when m == 1, tod < waketime for delayed processes
  proc get_time() returns time {
    time = tod;
  }
  proc delay(interval) {    # assume interval > 0
    int waketime = tod + interval;
    P(m);
    insert (waketime, myid) at appropriate place on napQ;     mutex
    V(m);
    P(d[myid]);   # wait to be awakened
  }
```

(And00 Fig 8.1)

(process Clock{} on next slide)

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```
  process Clock {
    start hardware timer;
    while (true) {
      wait for interrupt, then restart hardware timer;
      tod = tod+1;
      P(m);
      while (tod >= smallest waketime on napQ) {
        remove (waketime, id) from napQ;
        V(d[id]);  # awaken process id
      }
      V(m);
    }
  }
end TimeServer
```

- Internal process
  - Keeps the time
  - Wakes up delayed clients
- Service RPC's: time = TimeServer.get_time(); TimeServer.delay(10);

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Linux machine>> man rpc

RPC(3) RPC(3)

NAME
rpc - library routines for remote procedure calls

SYNOPSIS AND DESCRIPTION
These routines allow C programs to make procedure calls on other machines across the network. First, the client calls a procedure to send a data packet to the server. Upon receipt of the packet, the server calls a dispatch routine to perform the requested service, and then sends back a reply. Finally, the procedure call returns to the client.

```
callrpc(host, prognum, versnum, procnum, inproc, in, outproc, out)
  char *host;
  u_long prognum, versnum, procnum;
  char *in, *out;
  xdrproc_t inproc, outproc;
```

remote process

decode/encode parameters/results

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## Remote Method Invocation (RMI)

rmi server

```
package example.hello;

import java.rmi.Remote;
import java.rmi.RemoteException;

public interface Hello extends Remote {
    String sayHello() throws RemoteException;
}
```

http://java.sun.com/j2se/1.5.0/docs/guide/rmi/hello/hello-world.html

- Java RPC
- Start rmiregistry — rmiregistry & — start rmiregistry
  - Stub lookup (default at port 1099)
- Start rmi server
  - Server runs until explicitly terminated by user

java -classpath *classDir* example.hello.Server &

start java -classpath *classDir* example.hello.Server

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rmi server

```
package example.hello;
import java.rmi.registry.Registry;
import java.rmi.registry.LocateRegistry;
import java.rmi.RemoteException;
import java.rmi.server.UnicastRemoteObject;
public class Server implements Hello {
    public Server() {}
    public String sayHello() {
        return "Hello, world!"; }
    public static void main(String args[]) {
        try { Server obj = new Server();
            Hello stub = (Hello) UnicastRemoteObject.exportObject(obj, 0);
                // Bind the remote object's stub in the registry
            Registry registry = LocateRegistry.getRegistry();
            registry.bind("Hello", stub);
            System.err.println("Server ready");
        }   catch (Exception e) {
            System.err.println("Server exception: " + e.toString());
            e.printStackTrace();
        }
}
```

Output: Server ready

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rmi client

```
package example.hello;
import java.rmi.registry.LocateRegistry;
import java.rmi.registry.Registry;

public class Client {
    private Client() {}
    public static void main(String[] args) {
        String host = (args.length < 1) ? null : args[0];
        try {
            Registry registry = LocateRegistry.getRegistry(host);
            Hello stub = (Hello) registry.lookup("Hello");
            String response = stub.sayHello();
            System.out.println("response: " + response);
        } catch (Exception e) {
            System.err.println("Client exception: " + e.toString());
            e.printStackTrace();
        }
    }
}
```

Output: response: Hello, world!

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## Summary

- Distributed communication with messages
  - Synchronization and communication
  - Computation time + communication time = ?
- Higher level concepts
  - Guarded commands (theoretical background)
  - CSP (idea) & Occam (application)
  - Named Channels (ok without shared memory?)
  - Rendezvous
  - RPC & RMI (Java)

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