

# Concurrent Programming

## CS511

# About Erlang

- ▶ Functional language
- ▶ Concurrent/Distributed
  - ▶ No shared memory<sup>1</sup> (message passing)
- ▶ No types at compile time
  - ▶ Dynamically typed
- ▶ Open source
- ▶ Developed in the 80s in Ericsson by Joe Armstrong, Robert Virding and Mike Williams

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<sup>1</sup>Except for process dictionaries

# Runtime System

- ▶ Compiled code runs on a virtual machine (BEAM).
- ▶ Lightweight processes
- ▶ Fast process creation
- ▶ Support hot-swapping

# More About Erlang

- ▶ Open Telecom Platform (OTP) (fault-tolerance, hot code update, ...)
  - ▶ Practically “proven” programming patterns
- ▶ Supporting tools
  - ▶ Debugger
  - ▶ Unit testing
  - ▶ Dialyzer
  - ▶ Mnesia

# Typical Applications

- ▶ Telecoms
  - ▶ Switches (POTS, ATM, IP, ...)
  - ▶ GPRS
  - ▶ SMS applications
- ▶ Internet applications
  - ▶ WhatsApp (backbone)
  - ▶ Facebook (chat)
  - ▶ Amazon (SimpleDB, part of the Amazon Elastic Compute Cloud)
  - ▶ Yahoo! (social bookmarking service, Delicious)
  - ▶ Online shopping (Klarna AB)
  - ▶ T-Mobile
  - ▶ Discord
- ▶ 3D modelling (Wings3D)

# Bibliography

- ▶ [Programming Erlang: Software for a Concurrent World](#), Joe Armstrong



- ▶ [Learn some Erlang for Great Good!](#), Fred Hebert
- ▶ [Erlang Programming](#), Cesarini and Thompson

Note: Some of the material in these slides draw from the above sources

# Downloading and Installing

- ▶ <http://www.erlang.org/downloads>
- ▶ Prepackaged binaries from <https://www.erlang-solutions.com/resources/download.html>
- ▶ Setting up erlang mode in emacs+flycheck: <http://www.lambdacat.com/post-modern-emacs-setup-for-erlang/>

Erlang

Shell

Data Types

Modules



# Running Erlang

```
1 $ erl
2 Erlang/OTP 19 [erts-8.0] [source-6dc93c1] [64-bit] [smp:4:4]
   [async-threads:10] [hipe] [kernel-poll:false]
3
4 Eshell V8.0 (abort with ^G)
5 1> io:format("Hello, world!~n").
6 Hello, world!
7 ok
8 2> q().
9 ok
10 $
```

# A Small Script

```
1 $ cat hello.erl
2 %% Sample module
3 -module(hello).
4 -export([hello/0]).
5 hello() -> "Hello, world!".
6 $ erl
7 Erlang/OTP 19 [erts-8.0] [source-6dc93c1] [64-bit] [smp:4:4]
      [async-threads:10] [hipe] [kernel-poll:false]
8
9 Eshell V8.0 (abort with ^G)
10 1> c(hello).
11 {ok,hello}
12 2> hello:hello().
13 "Hello, world!"
14 3> q().
```

Mind the dot!

Erlang

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Data Types

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# Sequential Fragment

- ▶ Data types and variables
- ▶ Function definitions
- ▶ Pattern matching

# Numbers

## Integers (arbitrarily big)

```
1 7> fact:fact(200).
2 788657867364790503552363213932185062295135977687173263294742
3 533244359449963403342920304284011984623904177212138919638830
4 257642790242637105061926624952829931113462857270763317237396
5 988943922445621451664240254033291864131227428294853277524242
6 407573903240321257405579568660226031904170324062351700858796
7 1789222227896237038973747200000000000000000000000000000000000
8 0000000000000000
```

## Floats

```
1 > 2.78 + 9.6.
2 12.379999999999999
```

► IEEE 754 de 64-bits (range:  $\pm 10^{308}$ )

# Atoms

```
1 start_with_a_lower_case_letter  
2 'Anything_inside_quotes\n\09'
```

- ▶ Names must begin in lowercase or between apostrophes
- ▶ Heavily used

# Characters and Strings

► Characters: `$a`, `$n`.

► Strings

```
1 9> "hello".  
2 "hello"
```

► They are, in fact, a list of integers.

```
1 10> "hello\7".  
2 [104,101,108,108,111,7]  
3 11> is_list("hello").  
4 true
```

# Tuples

```
1 {}
2 {atom, another_atom, 'PPxT'}
3 {atom, {tup, 2}, {{tup}, element}}
4 {atom, {"hello",5}}
5
6 12> is_tuple({atom, another_atom, 'PPxT'}).
7 true
8 13> is_list({atom, another_atom, 'PPxT'}).
9 false
10 14> is_atom({atom, another_atom, 'PPxT'}).
11 false
```



# Modeling Data

```
type 'a tree = Leaf of 'a | Node of ('a tree)*('a tree)
```

- ▶ Atoms to indicate which constructor is used at top-level
- ▶ Tuples to collect the arguments of the constructor
- ▶ Example:

```
Node(Node(Leaf 3, Leaf 4), Leaf 5)
```

becomes

```
{node, {node, {leaf, 3}, {leaf, 4}}}, {leaf, 5}}
```

# Operators

- ▶ Arithmetic: `+`, `-`, `*`, `/`, `div`, `rem`
- ▶ Equal value: `"=="` and `"!="`
- ▶ Exact equality (type and value):  
`"==="` and `"!=="`
- ▶ Boolean: `and`, `or`, `xor`, `not`, `andalso`, `orelse`

# Operator Examples

```
1 1> 4 == 4.0.           % value is 4 on both sides
2 true
3 2> 4 == 4.0.           % value same but type different
4 false
5 3> 1 /= 0.
6 true
7 4> 1 /= 1.
8 false
9 5> 1 /= 1.0.
10 true.
```

- ▶ Use == and /=
- ▶ Switch to == and /= only when you need exact equality (type and value)

# Lists

```
1 []  
2 [1, true]  
3 [1 | [true] ]  
4 [ok, 10]
```

- ▶ List concatenation: “++”
- ▶ List subtraction: “--”
- ▶ List cons: “|”
- ▶ List comprehension: `[ math:log(A) || A <- lists:seq(1,10) ]`

# Operator and List Examples

```
1 3> L1 = [ apple, cherry ].
2 [apple, cherry]
3 4> L2 = [ lime, grape ].
4 [lime, grape]
5 5> L3 = L1 ++ L2.
6 [apple, cherry, lime, grape]
7 6> L3 -- [cherry].
8 [apple, lime, grape]
9 7> L4 = [ banana | L3 ].
10 [banana, apple, cherry, lime, grape]
11 8> [ Head | Tail ] = L4.
12 [banana, apple, cherry, lime, grape]
```

► Note: = is not assignment; it is **matching**

## Operator and List Examples (cont.)

```
1 9> b(). % b() shows all bindings
2 Head = banana % Head and Tail have been bound
3 L3 = [apple, cherry, lime, grape]
4 L4 = [banana, apple, cherry, lime, grape]
5 Tail = [apple, cherry, lime, grape]
6 ok
7 10> f(). % f() flushes all bindings
8 ok
9 11> { A, B } = { 4.0, 5.2 }.
10 {4.0, 5.2}
11 12> b().
12 A = 4.0
13 B = 5.2
14 13> { C, D } = { 4.0, 5.2 }.
15 {4.0, 5.2}
16 14> { A, B } == { C, D }.
17 true
18 15> { A, B } := { C, D }.
19 true
```

# Comparison

- ▶ In Erlang all terms are comparable

*number < atom < reference < fun < port < pid < tuple < map < nil < list < bitstring*

- ▶ Integers and floats are compared as usual
- ▶ The rest are compared as indicated above

```
1 1> a<2.  
2 false  
3 2> 2<a.  
4 true
```

# More on Variables

- ▶ Identifiers: `A_long_variable_name`
- ▶ Must start with an upper case letter
- ▶ Can store values
- ▶ Can be bound only once!
- ▶ Bound variables cannot change values
- ▶ We use the `=` operator for binding (and also matching!)



## More on Variables

```
1 1> a = 3.                                % fails because a is not a variable
2 ** exception error: no match of right hand side value 3
3 2> A = 3.                                % notice: ends with a period
4 3
5 3> B = 3.                                % there's that period again
6 3
7 4> A = B.                                % succeeds: A and B both have value 3
8 3
9 5> A = 4.                                % fails because A cannot be re-bound
10 ** exception error: no match of right hand side value 4
11 6> X = { hello, goodbye }.              % hello & goodbye are atoms
12 {hello,goodbye}
13 7> { Y, Z } = X.                        % binds both Y and Z
14 {hello,goodbye}
15 8> Y.
16 hello
17 9> Z.
18 goodbye
```

## More on Variables

```
1 10> X = {Y,Z}.           % succeeds because of value match
2 {hello,goodbye}
3 11> X = {hello,Z}.       % succeeds because of value match
4 {hello,goodbye}
5 12> q()                  % notice: forgot the period
6 12> q().                 % fails because Erlang reads "q()q() ."
7 * 2: syntax error before: q
8 13> q().                 % succeeds: quits Erlang shell
9 ok
```

# Functions

- ▶ May have several clauses
  - ▶ Function is sequence of pattern matching clauses separated by semicolons – semicolon means “or”
  - ▶ Finish definition with .
- ▶ Function application matches arguments to pattern in some clause

```
1 fact(0) -> 1;  
2 fact(N) when N>0 -> N * fact(N-1).
```

- ▶ “when ...” is a **clause guard**

# Example 1

```
1 arith(X, Y) ->
2   io:format("Arguments: ~p ~p~n", [ X, Y ]) ,
3   Sum = X + Y ,
4   Diff = X - Y ,
5   Prod = X * Y ,
6   Quo = X div Y ,
7   io:fwrite("~p ~p ~p ~p~n", [ Sum, Diff, Prod, Quo ]) ,
8   { Sum, Diff, Prod, Quo } .
```

Take note:

- ▶ Function name starts with lowercase letter
- ▶ `io:format` is similar to `printf`
- ▶ Expressions separated by comma
- ▶ Function clause ended by period
- ▶ Final expression is function's return value

## Example 2

```
1 what_day(saturday) -> % "saturday" is an atom
2     weekend ;          % notice semicolon
3 what_day(sunday) ->  % "sunday" is an atom
4     weekend ;          % semicolon again
5 what_day(_) ->        % underscore is "don't care" variable
6     weekday .         % period ends function
```

## Example 3

```
1 drivers_license(Age) when Age < 16 ->
2     forbidden ;
3 drivers_license(Age) when Age == 16 ->
4     'learners permit' ;
5 drivers_license(Age) when Age == 17 ->
6     'probationary license' ;
7 drivers_license(Age) when Age >= 65 ->
8     'vision test recommended but not required' ;
9 drivers_license(_) ->
10    'full license'.
```

# Function Application

- ▶ Function application is **call-by-value** or **eager**
- ▶ Clause matches if function name, arguments, and all guards match the input
- ▶ Except for “built-in functions (BIFs)” must specify function’s module when calling

```
1 2> drivers_license(16).  
2 ** exception error: undefined shell command  
   drivers_license/1  
3 3> example:drivers_license(16).  
4 'learners permit'
```

# Function Application

```
1 1> c(example).                % c() compiles
2 {ok,example}
3 2> drivers_license(16).        % must specify module
4 ** exception error: undefined shell command drivers_license
   /1
5 3> example:drivers_license(16).
6 'learners permit'
7 4> example:drivers_license(15).
8 forbidden
9 5> example:drivers_license(17).
10 'probationary license'
11 6> example:drivers_license(23).
12 'full license'
13 7> example:drivers_license(65).
14 'vision test recommended but not required'
15 8> q().
16 ok
```



# Pattern Matching

The factorial definition uses pattern matching over numbers

```
1 fact(0) -> 1;
2 fact(N) when N>0 -> N * fact(N-1).
```

- ▶ A zero number (first clause)
- ▶ A number different from zero (second clause)

A more involved example. Function area to compute the area of different geometrical figures.

```
1 area({square, Side}) -> Side * Side ;
2 area({circle, Radius}) -> Radius*Radius*math:pi().
```

- ▶ Patterns: `{square, Side}` and `{circle, Radius}`
- ▶ `{square, Side}` matches `{square, 4}` and binds 4 to variable `Side`
- ▶ `{circle, Radius}` matches `{circle, 1}` and binds 1 to variable `Radius`

# Anonymous Functions

```
1 11> F = fun (Y) -> Y+1 end.  
2 #Fun<erl_eval.6.127694169>  
3 12> F(2).  
4 3  
5 13> G = fun () -> 1 end.  
6 #Fun<erl_eval.20.127694169>  
7 14> G().  
8 1  
9 15> G.  
10 #Fun<erl_eval.20.127694169>  
11 16> [F,G].  
12 [#Fun<erl_eval.6.127694169>,#Fun<erl_eval.20.127694169>]
```

## Pattern Matching (cont.)

1 `{B, C, D} = {10, foo, bar}`

Succeeds: binds B to 10, C to foo and D to bar

1 `{A, A, B} = {abc, abc, foo}`

Succeeds: binds A to abc, B to foo

1 `{A, A, B} = {abc, def, 123}`

Fails

1 `[A,B,C,D] = [1,2,3]`

Fails

## Pattern Matching (cont.)

1  $[H|T] = [1,2,3,4]$

Succeeds: binds H to 1, T to [2,3,4]

1  $[H|T] = [abc]$

Succeeds: binds H to abc, T to []

1  $[H|T] = []$

Fails

1  $\{A, \_ , [B | \_ ] , \{B\} \} = \{abc, 23, [22, x] , \{22\}\}$

Succeeds: binds A to abc, B to 22

# BIFs

- ▶ Much-used modules in Erlang library: `io`, `list`, `dict`, `sets`, `gb_trees`
- ▶ You can inspect the source code for these libraries
- ▶ Eg. snippet from `/usr/local/lib/erlang/lib/stdlib-3.0/src/lists.erl`

```
1 %% sum(L) returns the sum of the elements in L
2 -spec sum(List) -> number() when
3     List :: [number()].
4
5 sum(L)                -> sum(L, 0).
6
7 sum([H|T], Sum) -> sum(T, Sum + H);
8 sum([], Sum)    -> Sum.
```

Erlang

Shell

Data Types

Modules

# Modules

- ▶ Basic compilation unit is a module
  - ▶ Module name = file name (.erl)
- ▶ They contain attributes and function definitions
- ▶ Attributes are of the form `-Name(Attribute).` and describe information about the module
- ▶ Let us create the module `math_examples` as follows.

```
1 -module(math_examples).
2 -export([fact/1,area/1]).
3 -author("E.B").
4
5 fact(0) -> 1;
6 fact(N) when N>0 -> N * fact(N-1).
7
8 area({square, Side}) -> Side*Side ;
9 area({circle, Radius}) -> Radius*Radius*math:pi().
```

# Modules

Running the examples.

```
1 1> c(math_examples).  
2 {ok,math_examples}  
3 2> math_examples:fact(3).  
4 6  
5 3> math_examples:area({square,4}).  
6 16  
7 4> math_examples:area({circle,1}).  
8 3.141592653589793
```



# Modules

- ▶ A useful compiler option is `export_all`

```
1 5> c(a_module,[export_all]).  
2 {ok,a_module}
```

- ▶ This causes the compiler to ignore the `-export` module attribute and export all functions defined
- ▶ You can also do the following:

```
1 -module(math_examples).  
2 -compile(export_all).  
3 -author("E.B").  
4  
5 fact(0) -> 1;  
6 fact(N) when N>0 -> N * fact(N-1).  
7  
8 area({square, Side}) -> Side*Side ;  
9 area({circle, Radius}) -> Radius*Radius*math:pi().
```

# Modules – Information About

```
1 1> c(math_examples).
2 {ok,math_examples}
3 2> math_examples:module_info().
4 [{module,math_examples},
5  {exports,[{fact,1},
6             {area,1},
7             {module_info,0},
8             {module_info,1}]}],
9  {attributes,[{vs_n,[292229879300425682399740783243125416564]}
10                ],
11                {author,"E.B"}]},
12  {compile,[{options,[]},
13            {version,"7.0"},
14            {source,"/Users/ebonelli/Documents/erlang/
15                  math_examples.erl"}]}],
16  {native,false},
17  {md5,<<219,217,109,113,225,135,117,96,156,42,192,248,50,
18      41,98,116>>}]
```

# Modules – Command Line

## ► Compilation

```
1 $ erlc math_examples.erl
```

This generates a bytecode file (i.e. `.beam` file)

## ► Execution

```
1 $ erl -noshell -run math_examples factLstStr 5 -run  
    init stop
```

`factStr` consumes a list of strings and then prints the result by calling `fact`

# Records

- ▶ Declared as module attributes

## Definition

```
-module(records).  
-compile(export_all).  
  
-record(robot, {name, type=industrial, hobbies, details=[]})  
.
```

## Creation

```
first_robot() ->  
    #robot{name="Mechatron", type=handmade,  
           details=["Moved by a small man inside"]}.  
.
```

# Records are Syntactic Sugar for Tuples

## Accessing record fields

```
1 1> c(records).
2 {ok, records}
3 2> records:first_robot().
4 {robot, "Mechatron", handmade, undefined, ["Moved by a small man
    inside"]}
```

- ▶ Note above: a record is just syntactic sugar for a tuple
- ▶ That means that if we try to access a field, we'll get an error

```
1 3> (records:first_robot())#robot.name.
2 * 1: record robot undefined
```

# Accessing the Fields

We must load the record definitions first

```
1 3> rr(records).
2 [robot]
3 4> records:first_robot().
4 #robot{name = "Mechatron",type = handmade,hobbies =
    undefined, details = ["Moved by a small man inside"]}

1 16> (records:first_robot())#robot.name.
2 "Mechatron"
3 17> Crusher = #robot{name="Crusher", hobbies=["Crushing
    people","petting cats"]}.
4 #robot{name = "Crusher",type = industrial,
5     hobbies = ["Crushing people","petting cats"],
6     details = []}
7 18> Crusher#robot.name.
8 "Crusher"
```

# Updating Records

```
1 repairman(Rob) -> Details = Rob#robot.details,  
2                   NewRob = Rob#robot{details=["Repaired by  
3 repairman"|Details]}, {repaired, NewRob}.  
  
1 16> c(records).  
2 {ok,records}  
3 17> records:repairman(#robot{name="Ulbert", hobbies=["trying  
4         to have feelings"]}).  
5 {repaired,#robot{name = "Ulbert",type = industrial, hobbies  
   = ["trying  
to have feelings"], details = ["Repaired by repairman"]}}
```

# Records in Header Files

```
1 %% this is a .hrl (header) file.  
2 -record(included, {some_field,  
3     some_default = "yeah!",  
4     unimaginative_name}).
```

To include it in `records.erl`, add the following line to the module:

```
1 -include("records.hrl").
```

And an example function

```
1 included() -> #included{some_field="Some value"}.
```



# Records in Header Files

```
1 18> c(records).  
2 {ok,records}  
3 19> rr(records).  
4 [included,robot,user]  
5 20> records:included().  
6 #included{some_field = "Some value",some_default = "yeah!",  
7 unimaginative_name = undefined}
```