

# Concurrent Programming

## CS511

(Lack of) Types

Documenting Types using `spec`

Tail Recursion

Exceptions

Control Structures

# Erlang is Strongly Typed

```
1 1> 6+"1".  
2 ** exception error: an error occurred when evaluating an  
3 arithmetic expression  
4     in operator +/2  
5     called as 6 + "1"
```

Good, but there is no static type-checking...

# Recall from Previous Class

```
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'.
```

# Types

```
1 2> c1:drivers_license(45).  
2 'full license'  
3 3> c1:drivers_license("hi").  
4 'vision test recommended but not required'
```

- ▶ What is going on?
- ▶ Recall the comparison order

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

```
1 ...  
2 drivers_license(Age) when Age >= 65 ->  
3   'vision test recommended but not required' ;  
4 ...
```

# Types

```
1 drivers_license(Age) when not(is_number(Age)) ->  
2     throw(wrong_argument_type);  
3 drivers_license(Age) when Age < 16 ->  
4     forbidden ;  
5 % the rest follows without change
```

► Other type-checking predicates:

is\_atom/1, is\_function/1, is\_boolean/1, is\_record/1,...

► More on exceptions later

```
1 9> c1:drivers_license("hi").  
2 ** exception throw: wrong_argument_type  
3     in function    c1:drivers_license/1 (c1.erl, line 6)
```

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# Documenting Types

- ▶ Type specifications:

  - spec Function(ArgType1, ..., ArgTypeN)->ReturnType.

  - or

  - spec Function(ArgName1 :: Type1, ..., ArgNameN :: TypeN)->RT

- ▶ Type specifiers are used for:

  - ▶ Documentation of intended usage
  - ▶ Automatic detection of type errors

- ▶ The compiler does not check type but there are tools for doing this



# Type Declarations – Examples

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

# Dialyzer

- ▶ Checks that given specifications agree with call patterns
  - ▶ Also detects exceptions and dead code
- ▶ It does so loosely using so called “Success Typings”  
[http://www.it.uu.se/research/group/hipe/papers/succ\\_types.pdf](http://www.it.uu.se/research/group/hipe/papers/succ_types.pdf)
  - ▶ Assume that all is good in terms of typing (start from most general possible type) and then refining this view as the code analysis progresses

# Dialyzer

- ▶ Before using this tool you must initialize its internal tables (Persistent Lookup Tables)
- ▶ This process can take 5 minutes or more

```
1 $ dialyzer --build_plt --apps erts kernel stdlib crypto
   mnesia sasl common_test eunit
2   Creating PLT /Users/ebonelli/.dialyzer_plt ...
3   Unknown functions:
4     compile:file/2
5     compile:forms/2
6     compile:noenv_forms/2
7     compile:output_generated/1
8     cover:analyse/2
9     cover:analyse_to_file/2
10    cover:analyse_to_file/3
11    cover:compile_beam/1
12    cover:export/1
13    cover:get_main_node/0
14    cover:import/1
15    cover:imported_modules/0
16    cover:start/0
17    cover:start/1
18    cover:stop/0
19    cover:stop/1
20    cover:which_nodes/0
```

# Checking Type Declarations

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

We check our code with dialyzer

```
1 $ dialyzer c1.erl
2   Checking whether the PLT /Users/ebonelli/.dialyzer_plt is
   up-to-date... yes
3   Proceeding with analysis... done in 0m1.03s
4 done (passed successfully)
```

# Checking Type Declarations

```
1 -spec drivers_license(integer()) -> string().  
2  
3 drivers_license(Age) when Age < 16 ->  
4     forbidden ;  
5 %...other clauses here...
```

We check our code with dialyzer

```
1 $ dialyzer c1.erl  
2   Checking whether the PLT /Users/ebonelli/.dialyzer_plt is  
   up-to-date... yes  
3   Proceeding with analysis...  
4 c1.erl:5: Invalid type specification for function c1:  
   drivers_license/1. The success typing is (_) -> '  
   forbidden' | 'full license' | 'learners permit' | '  
   probationary license' | 'vision test recommended but not  
   required'  
5   done in 0m1.09s  
6   done (warnings were emitted)
```

# Checking Type Declarations

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

We check our code with dialyzer

```
1 $ dialyzer c1.erl
2   Checking whether the PLT /Users/ebonelli/.dialyzer_plt is
   up-to-date... yes
3   Proceeding with analysis... done in 0m0.99s
4 done (passed successfully)
```

# Type Declarations – More Examples

- ▶ Type variables can be used in specifications to specify relations for the input and output arguments of a function
- ▶ For example, the following specification defines the type of a polymorphic identity function:  

```
-spec id(X) -> X.
```
- ▶ Notice that the above specification does not restrict the input and output type in any way

## Type Declarations – More Examples

- ▶ Type variables can be constrained using a when clause
- ▶ The `::` constraint should be read as “is a subtype of”

```
1 %% sum(L) returns the sum of the elements in L
2 -spec sum(List) -> number() when
3     List :: [number()].
4
5 %% min(L) -> returns the minimum element of the list L
6 -spec min(List) -> Min when
7     List :: [T,...],
8     Min :: T,
9     T :: term().
10
11 %% append(X, Y) appends lists X and Y
12 -spec append(List1, List2) -> List3 when
13     List1 :: [T],
14     List2 :: [T],
15     List3 :: [T],
16     T :: term().
```



# Type Expressions 1/3

- ▶ Singletons can be either integers or atoms:
  - ▶ 1, 2 or 42
  - ▶ 'foo', 'bar' or 'atom'
  - ▶ foo, 42
- ▶ Unions of singletons, what we normally refer to as “types”:
  - ▶ integer(): any integer value
  - ▶ float(): any floating point value
  - ▶ atom(): any atom
  - ▶ pid(): a process identifier
  - ▶ ref(): a reference
  - ▶ fun(): a function
  - ▶ ... and many more

## Type Expressions 2/3

- ▶ Types for compound data structures:
  - ▶ `tuple()`: a tuple of any form
  - ▶ `list()`: a proper list of any length
- ▶ Union type constructor
  - ▶ `type | type`

```
1 -spec f('a' | 1) -> 'b' | 1.  
2 f(1) ->  
3     1;  
4 f(a) ->  
5     b.
```

## Type Expressions 3/3

Some built-in types and how they are defined<sup>1</sup>:

<code>term()</code>	<code>any()</code>
<code>boolean()</code>	<code>'false'</code> — <code>'true'</code>
<code>byte()</code>	<code>0..255</code>
<code>char()</code>	<code>0..16#10ffff</code>
<code>nil()</code>	<code>[]</code>
<code>number()</code>	<code>integer()</code> — <code>float()</code>
<code>list()</code>	<code>[any()]</code>
<code>nonempty_list()</code>	<code>nonempty_list(any())</code>
<code>string()</code>	<code>[char()]</code>
<code>nonempty_string()</code>	<code>[char(),...]</code>
<code>function()</code>	<code>fun()</code>
<code>module()</code>	<code>atom()</code>
<code>no_return()</code>	<code>none()</code>

---

<sup>1</sup>[http://erlang.org/doc/reference\\_manual/typespec.html](http://erlang.org/doc/reference_manual/typespec.html)

# Defining Types – An Example

## ► Use of `type` directive

```
1  %%% {empty}      -- Empty tree
2  %%% {node,Data, LeftTree, RightTree}  -- Non empty tree
3
4  -type btree() :: {empty} | {node,term(),btree(),btree()}.
5
6  -spec sizeT(btree()) -> number().
7
8  sizeT({empty}) ->
9      0;
10 sizeT({node,_D,LT,RT}) ->
11     1 + sizeT(LT) + sizeT(RT).
```

## Defining Types – Another Example

We would like to define our own type that specifies what a card looks like.

```
1 -type value() :: 1..13.  
2 -type suit() :: spade | heart | diamond | clubs.  
3 -type card() :: {card, suit(), value()}.  
4 -spec suit(card()) -> suit().
```

Define the type of a deck of cards.

```
1 -type deck() :: list(card())
```

# An Example

```
1 -module(cards).
2 -export([kind/1, main/0]).
3
4 -type suit() :: spades | clubs | hearts | diamonds.
5 -type value() :: 1..10 | j | q | k.
6 -type card() :: {suit(), value()}.
7
8 kind({_, A}) when A >= 1, A =< 10 -> number;
9 kind(_) -> face.
10
11 main() ->
12 number = kind({spades, 7}),
13 face    = kind({hearts, k}),
14 number = kind({rubies, 4}),
15 face    = kind({clubs, q}).

1 1> c1:main().
2 face
```

Somewhat unexpected...

# An Example

```
1 $ dialyzer c1.erl
2   Checking whether the PLT /Users/ebonelli/.dialyzer_plt is
   up-to-date... yes
3   Proceeding with analysis...
4   done in 0m1.33s
5 done (warnings were emitted)
```

According to Dialyzer, everything is ok.

# An Example

```
1 -module(cards).
2 -export([kind/1, main/0]).
3
4 -type suit() :: spades | clubs | hearts | diamonds.
5 -type value() :: 1..10 | j | q | k.
6 -type card() :: {suit(), value()}.
7
8 -spec kind(card()) -> face | number.
9 kind({_, A}) when A >= 1, A =< 10 -> number;
10 kind(_) -> face.
11
12 main() ->
13 number = kind({spades, 7}),
14 face    = kind({hearts, k}),
15 number = kind({rubies, 4}),
16 face    = kind({clubs, q}).
```



# An Example

```
1 $ dialyzer c1.erl
2   Checking whether the PLT /Users/ebonelli/.dialyzer_plt is
   up-to-date... yes
3   Proceeding with analysis...
4 c1.erl:34: Function main/0 has no local return
5 c1.erl:37: The call c1:kind({'rubies',4}) breaks the
   contract (card()) -> 'face' | 'number'
6   done in 0m1.02s
7 done (warnings were emitted)
```

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# List Examples

```
1 > c(list_examples).
2 {ok, list_examples}
3 > list_examples:sum([1,2,3,4]).
4 10
5 > list_examples:len([0,1,0,1]).
6 4
7 > list_examples:append([5,4],[1,2,3]).
8 [5,4,1,2,3]
```

- ▶ We will define them recursively (inductively)
  - ▶ Base case: empty list (`[]`)
  - ▶ Recursive case: a list with at least one element (`[x | xs]`)

# Tail Recursion

- ▶ Programming pattern to increase performance
- ▶ It helps compilers when optimizing code
- ▶ Inefficient recursive definition

```
1 len([_|XS]) -> 1 + len(XS) ;  
2 len([])      -> 0.
```

Observe the evaluation of `len([1,2,3])`

```
1 len([1,2,3]) == 1 + len([2,3])  
2 len([1,2,3]) == 1 + (1 + len([3]))  
3 len([1,2,3]) == 1 + (1 + (1 + len([]))) %%  
4 len([1,2,3]) == 1 + (1 + (1 + 0))  
5 len([1,2,3]) == 1 + (1 + 1)  
6 len([1,2,3]) == 1 + 2  
7 len([1,2,3]) == 3
```

- ▶ At the time of reaching the marked line, Erlang needs to keep in memory a long expression
- ▶ After that line, it starts shrinking the expression
- ▶ Imaging how it will work for a very big list!

# Tail Recursion

- ▶ More efficiency by tail recursion
- ▶ Space (constant if we assume elements of the list have the same size)
- ▶ Efficiency (No returns from recursive calls)
- ▶ What is the trick?
  - ▶ Use of accumulators (partial results)
  - ▶ There are no more computations after the recursive call

# Tail Recursion

- ▶ We define `len_a`, the tail recursive version of `len`
- ▶ Function `len_a` has an extra parameters capturing the partial result of the function, i.e., how many elements `len_a` has seen so far

```
1 len_a([_|XS], Acc) -> len_a(XS, Acc+1);  
2 len_a([], Acc) -> Acc.
```

We define `len` based on `len_a` as follows

```
1 len(XS) -> len_a(XS, 0).
```

What about the tail recursive version of `sum` and `append`?

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# Exceptions

Three kinds:

- ▶ errors: run-time errors such as `1+a`; can be emulated with `error(Reason)`
- ▶ exits: generated error; generated by a process using `exit/1`
  - ▶ Studied next class
- ▶ throws: generated error; generated by a process using `throw/1`
  - ▶ Brief overview next



# Throw Exceptions

- ▶ Used for cases that the programmer can be expected to handle
- ▶ In comparison with exits and errors, they don't really carry any 'crash that process!' intent behind them, but rather control flow
- ▶ Good idea to document their use within a module using them

```
1 1> throw(permission_denied).  
2 ** exception throw: permission_denied
```

# Try...Catch

```
1 -module(exception).
2 -compile(export_all).
3
4 throws(F) ->
5     try F() of
6         _ -> ok
7     catch
8         Throw -> {throw, caught, Throw}
9     end.

1 1> c(exception).
2 {ok,exception}
3 2> exception:throws(fun() -> throw(throw) end).
4 {throw,caught,throw}
5 3> exception:throws(fun() -> erlang:error(pang) end).
6 ** exception error: pang
```

# Try..Catch

```
1 talk() -> "blah blah".
2
3 sword(1) -> throw(slice);
4 sword(2) -> erlang:error(cut_arm);
5 sword(3) -> exit(cut_leg);
6 sword(4) -> throw(punch);
7 sword(5) -> exit(cross_bridge).
8
9 black_knight(Attack) when is_function(Attack, 0) ->
10     try Attack() of
11         _ -> "None shall pass."
12     catch
13         throw:slice -> "It is but a scratch.";
14         error:cut_arm -> "I've had worse.";
15         exit:cut_leg -> "Come on you pansy!";
16         _:_ -> "Just a flesh wound."
17     end.
```

# Try-Catch

```
1 7> c(exception).
2 {ok,exceptions}
3 8> exceptions:talk().
4 "blah blah"
5 9> exceptions:black_knight(fun exceptions:talk/0).
6 "None shall pass."
7 10> exceptions:black_knight(fun() -> exceptions:sword(1) end
8 ).
9 "It is but a scratch."
10 11> exceptions:black_knight(fun() -> exceptions:sword(2) end
11 ).
12 "I've had worse."
13 12> exceptions:black_knight(fun() -> exceptions:sword(3) end
14 ).
15 "Come on you pansy!"
16 13> exceptions:black_knight(fun() -> exceptions:sword(4) end
17 ).
18 "Just a flesh wound."
19 14> exceptions:black_knight(fun() -> exceptions:sword(5) end
20 ).
21 "Just a flesh wound."
```

# Additional Constructs

```
1 try Expr of
2   Pattern -> Expr1
3 catch
4   Type:Exception -> Expr2
5 after % this always gets executed
6   Expr3
7 end
```

- ▶ Expr3 is always run, be there an exception or not

# Additional Constructs

```
1 1> catch throw(whoa).
2 whoa
3 2> catch exit(die).
4 {'EXIT',die}
5 3> catch 1/0.
6 {'EXIT',{badarith,[{erlang,'/',[1,0]},
7 {erl_eval,do_apply,5},
8 {erl_eval,expr,5},
9 {shell,exprs,6},
10 {shell,eval_exprs,6},
11 {shell,eval_loop,3}]}}
12 4> catch 2+2.
13 4
```

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# Control Structures

```
1 is_greater_than(X, Y) ->
2     if
3         X>Y ->
4             true;
5         true -> % works as an 'else' branch
6             false
7     end
```



# Control Structures

```
1 is_valid_signal(Signal) ->
2     case Signal of
3         {signal, _What, _From, _To} ->
4             true;
5         {signal, _What, _To} ->
6             true;
7         _Else ->
8             false
9     end.
```