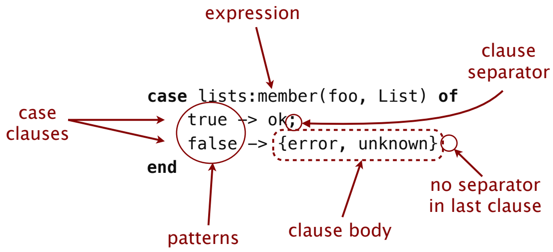
Erlang Solutions Ltd.

Sequential Erlang

Overview: sequential Erlang I

- Sequential Erlang I
  - Conditional Evaluation
  - Guards
  - Recursion
- Sequential Erlang II
- Sequential Erlang III

Conditional Evaluation: case



```
case lists:member(foo, List) of
    true  -> ok;
    false -> {error, unknown}
end
```

Conditional evaluation: case

```
case <expression> of
    Pattern1 ->
        <expression 1>,
        <expression 2>,
        ...
        <expression N>;
   Pattern2 ->
        <expression 1>,
        <expression 2>,
        ...
        <expression N>;
   _ ->
        <expression 1>,
        ...
        <expression N>
end
```

- One branch should always succeed
- Using an unbound variable or '_' ensures that the clause will always match
- The _ clause is not mandatory
- An exception is raised if no clause matches
- Returns the value of the last executed expression

Defensive Programming

```
convert(Day) ->
  case Day of
      monday    -> 1;
      tuesday   -> 2;
      wednesday -> 3;
      thursday  -> 4;
      friday    -> 5;
      saturday  -> 6;
      sunday    -> 7;
      Other ->
         {error, unknown_day}
  end.
```

- Defensive programming: program in the convert function for the error case or ...
- ... let it fail here by deleting the **Other** clause.
- This will raise an exception
- The caller will have to handle the error that they have caused.

Guards

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


 This is NOT the same as...

factorial(0) -> 1;
factorial(N) ->
    N * factorial(N - 1).
```

- The reserved word **when** introduces a guard
- Fully guarded clauses can be re-ordered
- Guards can be used in function heads, case clauses, receive and if expressions.

Guards: **examples**

```
number(Num) when is_integer(Num) -> integer;
number(Num) when is_float(Num) -> float;
number(_Other) -> false.
```

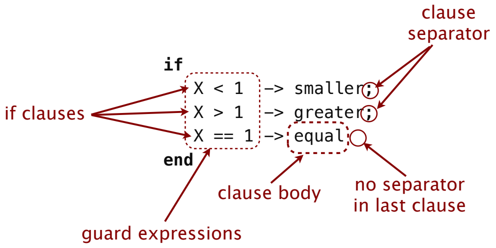
- is_number(X), is_integer(X), is_float(X)
  - X is a number
- is_atom(X), is_pid(X), is_tuple(X), is_list(X)
  - X is the specified datatype
- length(List) == Int, tuple_size(Tuple) == Size, X > Y + Z
  - Some BIFs and mathematical applications can be applied in guards
- X == Y   X /= Y   X =:= Y   X =/= Y
  - X is (not) equal to Y, X is exactly (not) equal to Y (1==1.0 ✓, 1=:=1.0 ×)
- X =< Y   X >= Y
  - NB, not <= or =>

Guards

```
valid_age(Age) when Age >= 18, Age =< 99 ->
    true;
valid_age(_) ->
    false.
```

- All variables in guards have to be bound
- Guards have to be free of side effects
- If all the guards have to succeed, use **,** to separate them
- If one guard has to succeed, use **;** to separate them
- There are restrictions on BIFs and expressions in guards
  - See the Erlang reference manual for complete details

Conditional Evaluation: **if**



Conditional Evaluation: **if**

```
if Guard1 ->
       <expression 1>,
       <expression 2>,
       ...
       <expression N>;
   Guard2 ->
       <expression 1>,
       <expression 2>,
       ...
       <expression N>;
   ...
   true ->
       <expression 1>,
       ...
       <expression N>
end
```

- One branch must always succeed
- By using **true** as the last guard, we ensure that a clause will always succeed
- The **true** guard is not mandatory
- An exception is raised if no clause succeeds
- Returns the value of the last executed expression

General Switch

```
if f(Args) -> ok;                X
   true    -> error
end
case f(Args) of
    true -> ok;                  ✓
    false -> error
end
```

- The if construct fails because it involves a user-defined function, which are forbidden in guards
- The case construct succeeds because it accepts user-defined functions.

Recursion: **traversing lists**

```
average(X) -> sum(X) / len(X).

sum([H|T]) -> H + sum(T);
sum([]) -> 0.

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

- Note the pattern of recursion is the same in both cases
- Taking a list and evaluating an element is a very common pattern

Recursion: self-describing code

```
sum([]) -> 0;

sum([H|T]) -> H + sum(T).
```

- You can read the programs as an executable description:
- "The sum of an empty list is 0."
- "The sum of a non-empty list is the head of the list added to the sum of the tail"

Recursion: traversing lists

```
printAll([]) ->
    io:format("~n", []);

printAll([X|Xs]) ->
    io:format("~p ", [X]),
    printAll(Xs).
```

- Here we're traversing the list imperatively:
- "If there are no more elements to process, stop"
- "If there are further elements, process the head, and then call the function recursively on the tail."

Recursion: traversing lists

```
printAll(Ys) ->
    case Ys of
      [] ->
        io:format("~n", []);
      [X|Xs] ->
        io:format("~p ", [X]),
        printAll(Xs)
    end.
```

- Same function again: shows the loop clearly. The call to **printAll(Xs)** is like a **jump** back to the top of the loop.
- This is a **tail recursive** function: the only recursive calls come at the end of the bodies of the clauses.

Recursion: more patterns

```
double([H|T])-> [2*H|double(T)];
double([]) -> [].

member(H, [H|_]) -> true;
member(H, [_|T]) -> member(H,T);
member(_, [])    -> false.

even([H|T]) when H rem 2 == 0 ->
    [H|even(T)];
even([_|T]) ->
    even(T);
even([]) ->
    [].
```

- **double/1** maps elements in a list and returns a new list
- **member/2** is a predicate looking for an element in a list
- **even/1** filters a list of integers and returns the subset of even numbers
- The function **member/2** is the only one which is tail recursive

Recursion: accumulators

```
average(X) -> average(X, 0, 0).

average([H|T], Length, Sum) ->
  average(T, Length+1, Sum+H);
average([], Length, Sum) ->
  Sum/Length.
```

- Only traverses the list once.
- Executes in constant space (tail recursive)
- **Length** and **Sum** play the role of accumulators
- **average([])** is not defined
- Evaluating **average([])** would cause a run time error.

Summary: sequential Erlang I

- Sequential Erlang I
  - Conditional evaluation
  - Guards
  - Recursion
- Sequential Erlang II
- Sequential Erlang III

Overview: sequential Erlang II

- Sequential Erlang I
- Sequential Erlang II
  - BIFs
  - Libraries
  - Manual Pages
  - The Debugger
- Sequential Erlang III

Built-in Functions

```
date()
time()
length(List)
size(Tuple)
atom_to_list(Atom)
list_to_tuple(List)
integer_to_list(2235)
tuple_to_list(Tuple)
```

- Do what you cannot do (or is difficult to do) in Erlang
- Mostly written in C for fast execution
- BIFs are by convention regarded as being in the **erlang** module.

Built-in Functions

- There are BIFs for:
  - Process and port handling
  - Object access and examination
  - Meta programming
  - Type conversion
  - System information
  - Distribution
  - Others
- For a complete list, see the manual page for the **erlang** module.

Built-in Functions

- Built-in functions can modify the real time properties of the system
- A process executing a BIF will not be suspended until the BIF has completed executing
- Other processes will thus not be allowed to execute on the same scheduler
- Use BIFs with care!

Built-in Functions: examples

```
1> date().
{2010,9,25}
2> atom_to_list(abcd).
"abcd"
3> tuple_to_list(list_to_tuple([1,2,3,4])).
[1,2,3,4]
4> length([1,2,3,4,5]).
5
```

Built-in Functions: meta calls

```
apply(Module, Function, Arguments)
M:function(Args)
M:F(Args)
```

- **apply/3** is a BIF used to dynamically evaluate functions
- The function must be exported
- The arguments can possibly be an empty list
- All the arguments can be established at runtime
- Extremely powerful when implementing generic code

Built-in Functions: meta calls

```
1> Module = io.
io
2> Function = format.
format
3> Arguments = ["Hello World~n", []].
["Hello World~n",[]]
4> apply(Module, Function, Arguments).
Hello World
ok
8> io:Function("Hello World ", []).
Hello World ok
9> Module:Function("Hello World ", []).
Hello World ok
```

The arguments to **apply** could have been evaluated during runtime

The arities of the **M:func(Args)** and **M:F(Args)** forms are static

Libraries

io.erl
generalised input/output functionality

file.erl
generalised interface towards the file system

lists.erl
standard list processing functions

code.erl
functionality to load, test and manipulate code.

math.erl
mathematical functions

Libraries

- Erlang has a set of libraries where functionality useful to the software designer has been placed
- The previous list of modules are all part of the standard Erlang/OTP distribution
- Many more libraries and modules are available:
  - They are referenced in the official documentation

Libraries

```
lists:append(List1, List2) -> NewList.
lists:delete(Element, List) -> NewList.
lists:last(List) -> Element.
lists:reverse(List) -> ReversedList.
lists:sort(List) -> SortedList.
lists:keysort(Pos, TupleList) -> SortedList.
lists:keydelete(Key, Pos, TupleList) -> NewList.
lists:keysearch(Key, Pos, TupleList) ->
    false | {value, Tuple}
```

- The lists module is the most used and one of the most useful ones

Manual Pages

In the UNIX shell
$ erl -man Module

In HTML
By accessing file://$ERL_ROOT/doc/index.html

In Emacs
Picking one of the entries under the Erlang menu

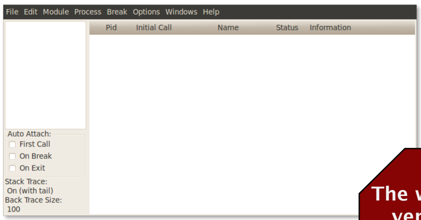
In General
Manual pages for all the modules can be read online, from the shell, in emacs or in the OTP reference manual.

Take a look at the available modules to get an idea of the existing functionality

The Debugger

- The Erlang debugger is a graphical tool providing mechanisms to debug code and influence program execution
  - Allows the user to insert break points
  - Step through the code
  - Inspect and manipulate variables
  - Inspecting the recursive stack

The Debugger



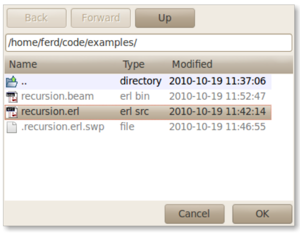
Auto Attach:
□ First Call
□ On Break
□ On Exit

Stack Trace:
On (with tail)
Back Trace Size:
100

The windows version is known to be unstable

- debugger:start()

The Debugger

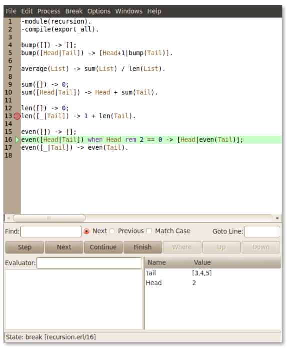


/home/ferd/code/examples/

Name	Type	Modified
..	directory	2010-10-19 11:37:06
recursion.beam	erl bin	2010-10-19 11:52:47
recursion.erl	erl src	2010-10-19 11:42:14
.recursion.erl.swp	file	2010-10-19 11:46:55

- Interpret the code
  - Must be compiled with the **debug_info** flag
  - use **c(Module, [debug_info])**

The Debugger



```
-module(recursion).
-compile(export_all).

bump([]) -> [];
bump([Head|Tail]) -> [Head+1|bump(Tail)].

average(List) -> sum(List) / len(List).

sum([]) -> 0;
sum([Head|Tail]) -> Head + sum(Tail).

len([]) -> 0;
len([_|Tail]) -> 1 + len(Tail).

even([]) -> [];
even([Head|Tail]) when Head rem 2 == 0 -> [Head|even(Tail)];
even([_|Tail]) -> even(Tail).
```

Name	Value
Tail	[3,4,5]
Head	2

State: break [recursion.erl/16]

- Stepping through the code

Summary: sequential Erlang II

- Sequential Erlang I
- Sequential Erlang II
  - BIFs
  - Libraries
  - Manual Pages
  - The Debugger
- Sequential Erlang III

Overview: sequential Erlang III

- Sequential Erlang I
- Sequential Erlang II
- Sequential Erlang III
  - Run Time Errors
  - Try ... catch
  - Throw
  - Catch

Run Time Errors: match

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

- **function_clause** is returned when none of the existing function patterns matches

```
1> math:factorial(-1).
** exception error: no function clause matching
  math:factorial(-1)
```

Run Time Errors: match

```
test(N) ->
    case N of
        -1 -> false;
         1 -> true
    end.
```

- **case_clause** is returned when none of the existing patterns in the case statement matches

```
1> test:test(0).
** exception error: no case clause matching 0
     in function  test:test/1
```

Run Time Errors

```
test(N) ->
    if
       N < 0 -> false;
       N > 0 -> true
    end.
```

- **if_clause** is returned when none of the existing expressions in the if statement evaluates to **true**

```
1> test:test(0).
** exception error: no true branch found when evaluating
an if expression
     in function  test:test/1
```

Run Time Errors: match

```
1> Tuple = {1, two, 3}.
{1,two,3}
2> {1, two, 3, Four} = Tuple.
** exception error: no match of right hand side value
  {1,two,3}
```

- **badmatch** errors occur in situations when pattern matching fails and there are no other alternative clauses to choose from.

Run Time Errors: others

```
1> length(helloWorld).
** exception error: bad argument in function length/1
        called as length(helloWorld)
```

- **badarg** is returned when a BIF with wrong arguments is called.

Run Time Errors: others

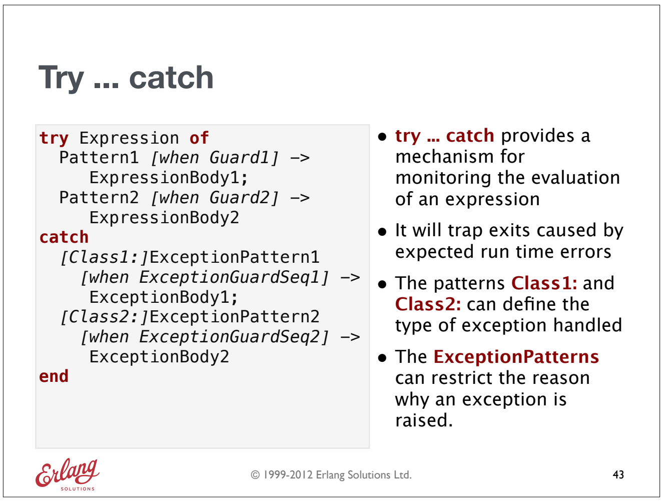
```
1> test:hello().
  ** exception error: undefined function test:hello/0
```

- **undef** will be returned if the global function being called is not defined or exported

Run Time Errors: others

```
1> 1 + a.
** exception error: bad argument in an arithmetic
expression
     in operator  +/2
        called as 1 + a
```

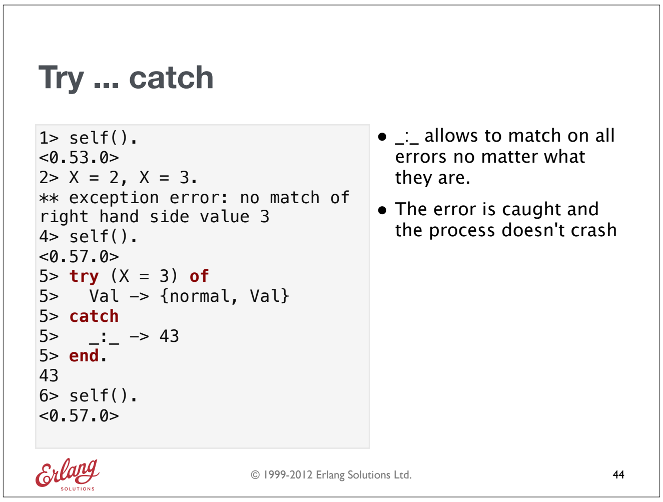
- **badarith** is returned when arithmetical operations are executed with values that are neither integers or floats.



Try ... catch

```
try Expression of
  Pattern1 [when Guard1] ->
     ExpressionBody1;
  Pattern2 [when Guard2] ->
     ExpressionBody2
catch
  [Class1:]ExceptionPattern1
    [when ExceptionGuardSeq1] ->
     ExceptionBody1;
  [Class2:]ExceptionPattern2
    [when ExceptionGuardSeq2] ->
     ExceptionBody2
end
```

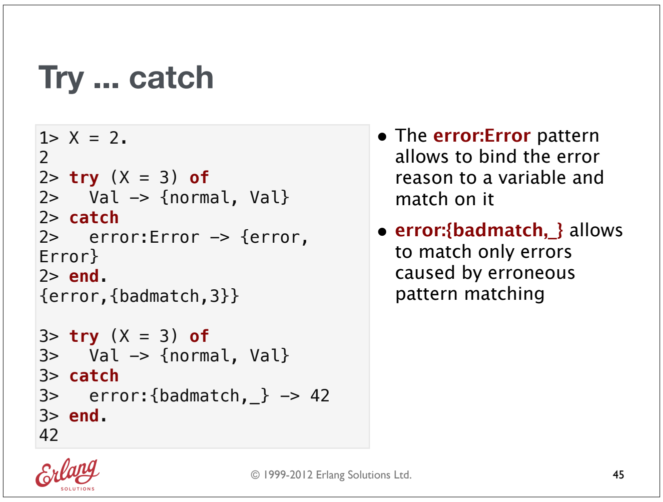
- **try ... catch** provides a mechanism for monitoring the evaluation of an expression
- It will trap exits caused by expected run time errors
- The patterns **Class1:** and **Class2:** can define the type of exception handled
- The **ExceptionPatterns** can restrict the reason why an exception is raised.



Try ... catch

```
1> self().
<0.53.0>
2> X = 2, X = 3.
** exception error: no match of
right hand side value 3
4> self().
<0.57.0>
5> try (X = 3) of
5>    Val -> {normal, Val}
5> catch
5>    _:_ -> 43
5> end.
43
6> self().
<0.57.0>
```

- _:_ allows to match on all errors no matter what they are.
- The error is caught and the process doesn't crash

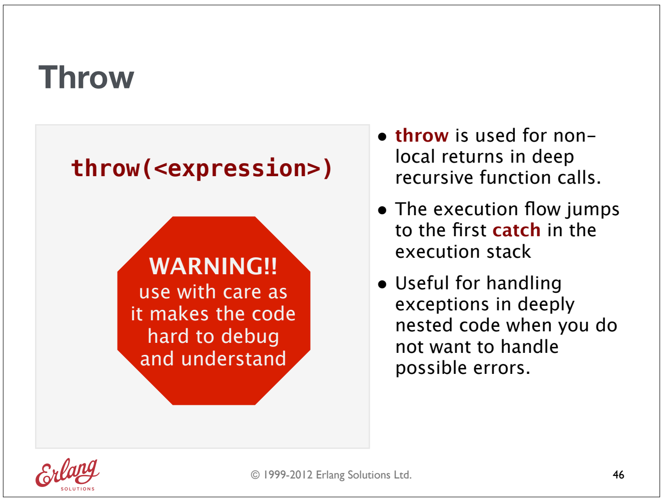


Try ... catch

```
1> X = 2.
2
2> try (X = 3) of
2>    Val -> {normal, Val}
2> catch
2>    error:Error -> {error,
Error}
2> end.
{error,{badmatch,3}}

3> try (X = 3) of
3>    Val -> {normal, Val}
3> catch
3>    error:{badmatch,_} -> 42
3> end.
42
```

- The **error:Error** pattern allows to bind the error reason to a variable and match on it
- **error:{badmatch,_}** allows to match only errors caused by erroneous pattern matching

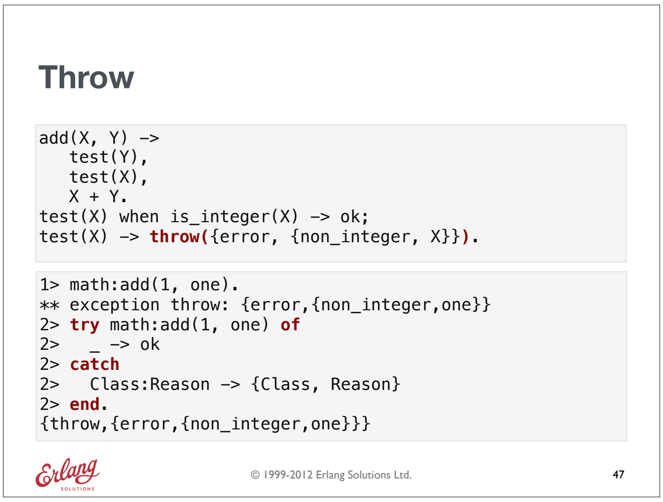


Throw

```
throw(<expression>)
```

WARNING!!
use with care as
it makes the code
hard to debug
and understand

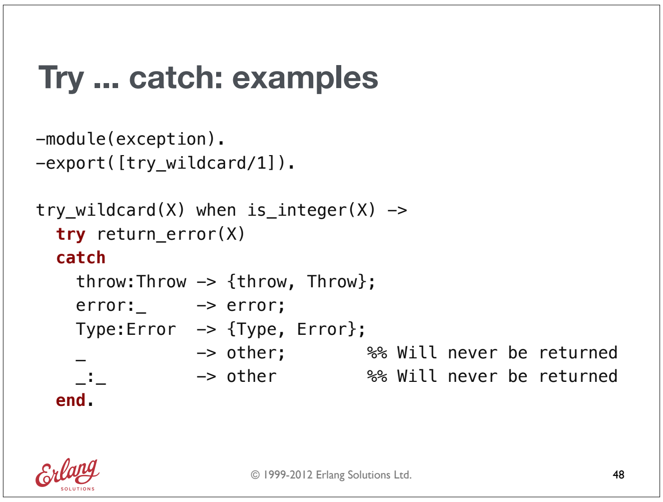
- **throw** is used for non-local returns in deep recursive function calls.
- The execution flow jumps to the first **catch** in the execution stack
- Useful for handling exceptions in deeply nested code when you do not want to handle possible errors.



Throw

```
add(X, Y) ->
   test(Y),
   test(X),
   X + Y.
test(X) when is_integer(X) -> ok;
test(X) -> throw({error, {non_integer, X}}).
```

```
1> math:add(1, one).
** exception throw: {error,{non_integer,one}}
2> try math:add(1, one) of
2>    _ -> ok
2> catch
2>    Class:Reason -> {Class, Reason}
2> end.
{throw,{error,{non_integer,one}}}
```



Try ... catch: examples

```
-module(exception).
-export([try_wildcard/1]).

try_wildcard(X) when is_integer(X) ->
  try return_error(X)
  catch
    throw:Throw -> {throw, Throw};
    error:_     -> error;
    Type:Error  -> {Type, Error};
    _           -> other;        %% Will never be returned
    _:_         -> other         %% Will never be returned
  end.
```

Try ... catch: examples

```
return_error(X) when X < 0 ->
  throw({'EXIT',{badarith,[{exception,return_error,1},
                           {erl_eval,do_apply,5},
                           {shell,exprs,6},
                           {shell,eval_exprs,6},
                           {shell,eval_loop,3}]}});
return_error(X) when X == 0 -> 1/X;
return_error(X) when X > 0 ->
  {'EXIT',{badarith,[{exception,return_error,1},
                     {erl_eval,do_apply,5},
                     {shell,exprs,6},
                     {shell,eval_exprs,6},
                     {shell,eval_loop,3}]}}.
```

Try ... catch: examples

```
1> exception:try_wildcard(-1).
{throw,{'EXIT',{badarith,[{exception,return_error,1},
                          {erl_eval,do_apply,5},
                          {shell,exprs,6},
                          {shell,eval_exprs,6},
                          {shell,eval_loop,3}]}}}
2> exception:try_wildcard(0).
error
3> exception:try_wildcard(1).
{'EXIT',{badarith,[{exception,return_error,1},
                   {erl_eval,do_apply,5},
                   ...
                   {shell,eval_loop,3}]}}
```

Catch

```
catch <expression>
```

- **catch** provides a mechanism for monitoring the evaluation of an expression
- It will trap exits caused by runtime errors
- A function call resulting in a run time error called in the scope or a catch will return the tuple **{'EXIT', Reason}**
- **Reason** is the runtime error which occurred

Catch

```
1> self().
<0.28.0>
2> catch list_to_integer("one").
{'EXIT',{badarg,[{erlang,list_to_integer,["one"]},
             ...,{shell,eval_loop,3}]}}
3> self().
<0.28.0>
4> list_to_integer("one").
** exception error: bad argument
     in function  list_to_integer/1
        called as list_to_integer("one")
5> self().
<0.33.0>
```

Catch

```
1> catch 1/0.
{'EXIT',{badarith,[{erlang,'/',[1,0]},
                   {erl_eval,do_apply,5},
                   {erl_eval,expr,5},
                   ...,
                   {shell,eval_loop,3}]}}
2> X = catch 1/0.
* 1: syntax error before: 'catch'
2> X = (catch 1/0).
{'EXIT',{badarith,[{erlang,'/',[1,0]},
                   {erl_eval,do_apply,5},
                   {erl_eval,expr,5},
                   ...
```

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  - Catch