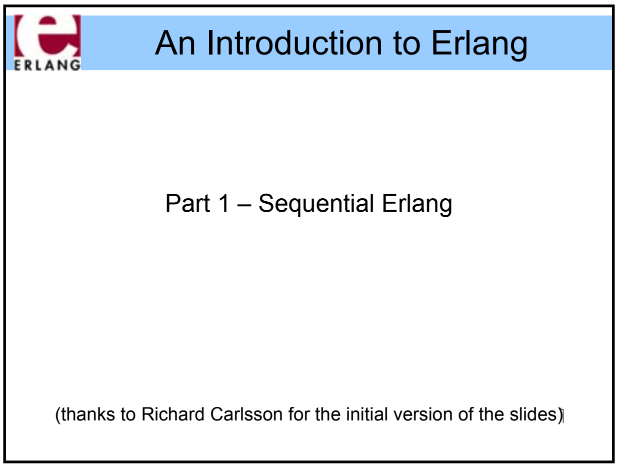
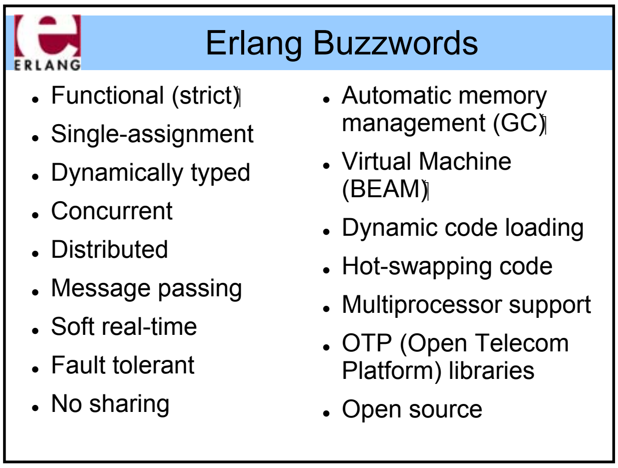


An Introduction to Erlang

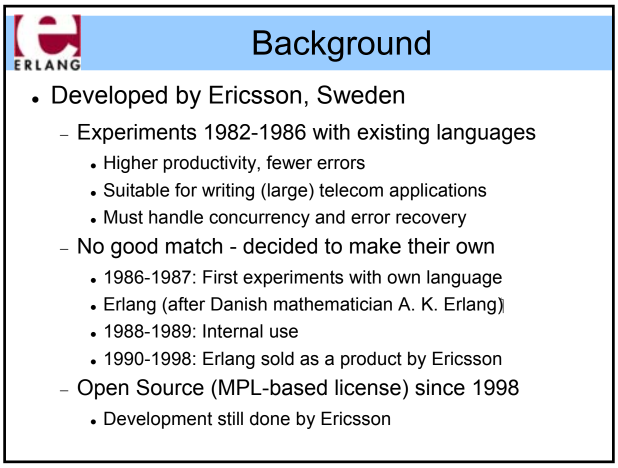
Part 1 – Sequential Erlang

(thanks to Richard Carlsson for the initial version of the slides)



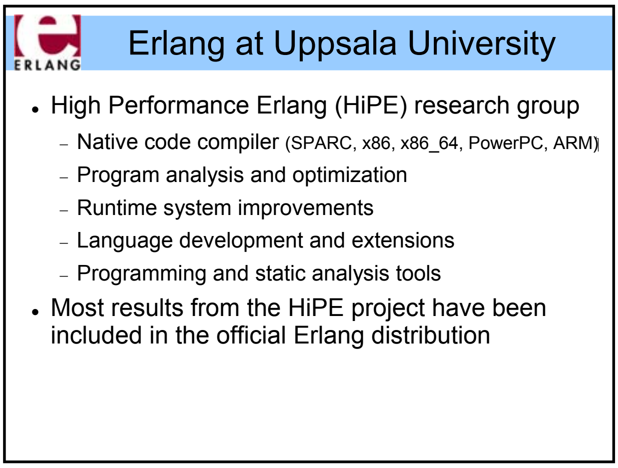
Erlang Buzzwords

- Functional (strict)
- Single-assignment
- Dynamically typed
- Concurrent
- Distributed
- Message passing
- Soft real-time
- Fault tolerant
- No sharing
- Automatic memory management (GC)
- Virtual Machine (BEAM)
- Dynamic code loading
- Hot-swapping code
- Multiprocessor support
- OTP (Open Telecom Platform) libraries
- Open source



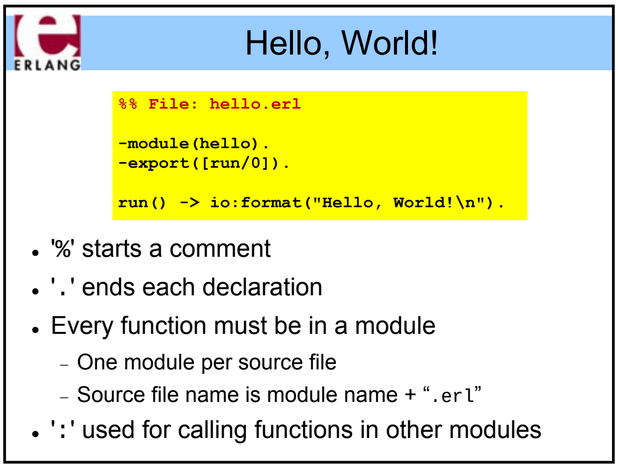
Background

- Developed by Ericsson, Sweden
  - Experiments 1982-1986 with existing languages
    - Higher productivity, fewer errors
    - Suitable for writing (large) telecom applications
    - Must handle concurrency and error recovery
  - No good match - decided to make their own
    - 1986-1987: First experiments with own language
    - Erlang (after Danish mathematician A. K. Erlang)
    - 1988-1989: Internal use
    - 1990-1998: Erlang sold as a product by Ericsson
  - Open Source (MPL-based license) since 1998
    - Development still done by Ericsson



Erlang at Uppsala University

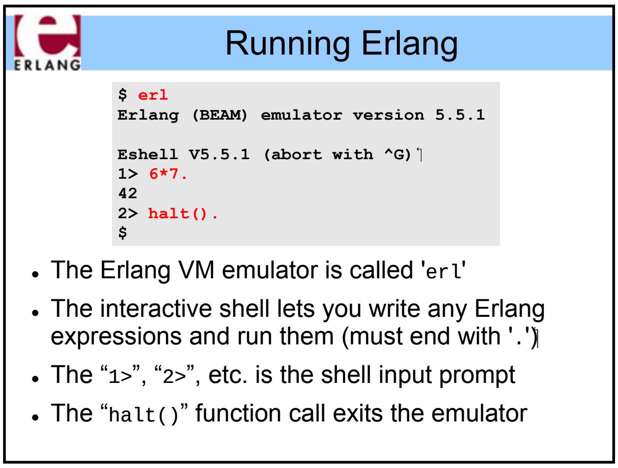
- High Performance Erlang (HiPE) research group
  - Native code compiler (SPARC, x86, x86_64, PowerPC, ARM)
  - Program analysis and optimization
  - Runtime system improvements
  - Language development and extensions
  - Programming and static analysis tools
- Most results from the HiPE project have been included in the official Erlang distribution



Hello, World!

```
%% File: hello.erl

-module(hello).
-export([run/0]).

run() -> io:format("Hello, World!\n").
```

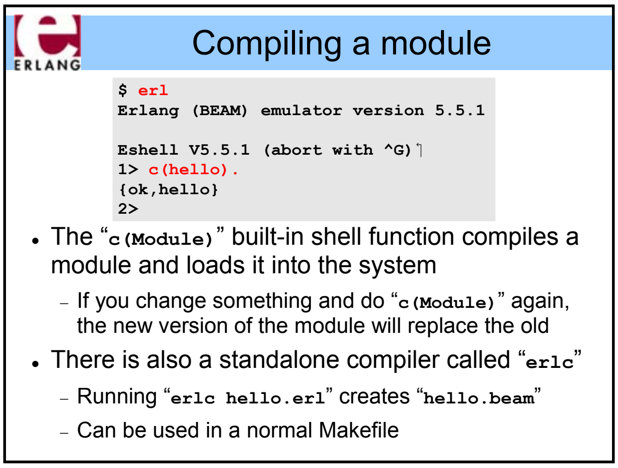
- '%' starts a comment
- '.' ends each declaration
- Every function must be in a module
  - One module per source file
  - Source file name is module name + ".erl"
- ':' used for calling functions in other modules



Running Erlang

```
$ erl
Erlang (BEAM) emulator version 5.5.1

Eshell V5.5.1 (abort with ^G)
1> 6*7.
42
2> halt().
$
```

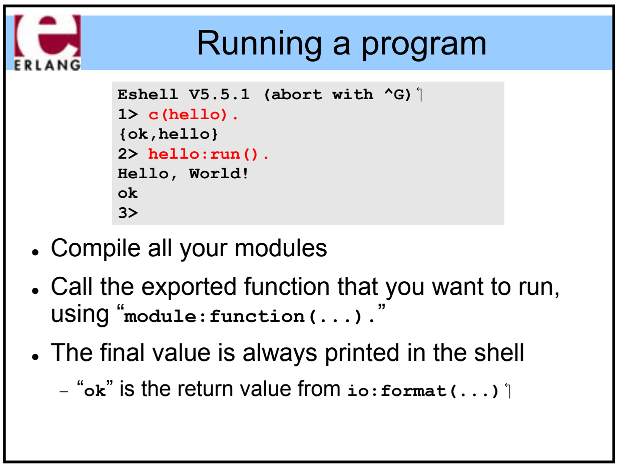
- The Erlang VM emulator is called 'erl'
- The interactive shell lets you write any Erlang expressions and run them (must end with '.')
- The "1>", "2>", etc. is the shell input prompt
- The "halt()" function call exits the emulator



Compiling a module

```
$ erl
Erlang (BEAM) emulator version 5.5.1

Eshell V5.5.1 (abort with ^G)
1> c(hello).
{ok,hello}
2>
```

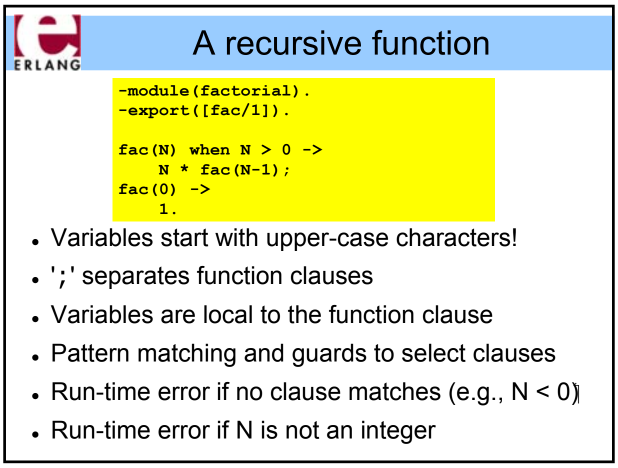
- The "`c(Module)`" built-in shell function compiles a module and loads it into the system
  - If you change something and do "`c(Module)`" again, the new version of the module will replace the old
- There is also a standalone compiler called "`erlc`"
  - Running "`erlc hello.erl`" creates "`hello.beam`"
  - Can be used in a normal Makefile



Running a program

```
Eshell V5.5.1 (abort with ^G)
1> c(hello).
{ok,hello}
2> hello:run().
Hello, World!
ok
3>
```

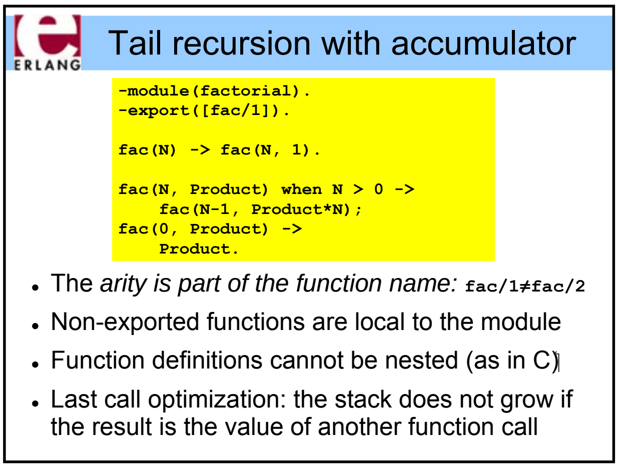
- Compile all your modules
- Call the exported function that you want to run, using "`module:function(...).`"
- The final value is always printed in the shell
  - "`ok`" is the return value from `io:format(...)`



A recursive function

```
-module(factorial).
-export([fac/1]).

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

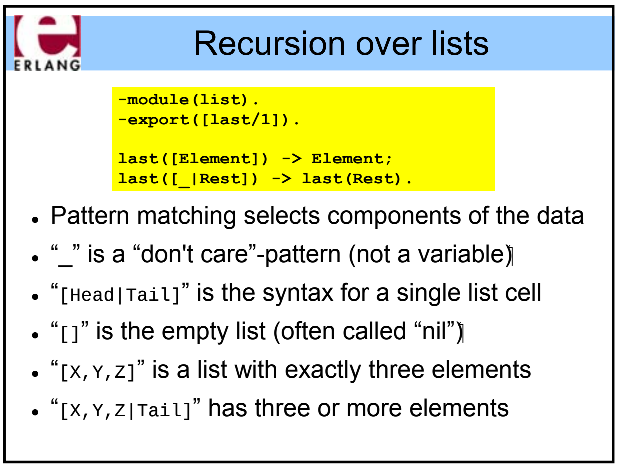
- Variables start with upper-case characters!
- ';' separates function clauses
- Variables are local to the function clause
- Pattern matching and guards to select clauses
- Run-time error if no clause matches (e.g., N < 0)
- Run-time error if N is not an integer



Tail recursion with accumulator

```
-module(factorial).
-export([fac/1]).

fac(N) -> fac(N, 1).

fac(N, Product) when N > 0 ->
     fac(N-1, Product*N);
fac(0, Product) ->
     Product.
```

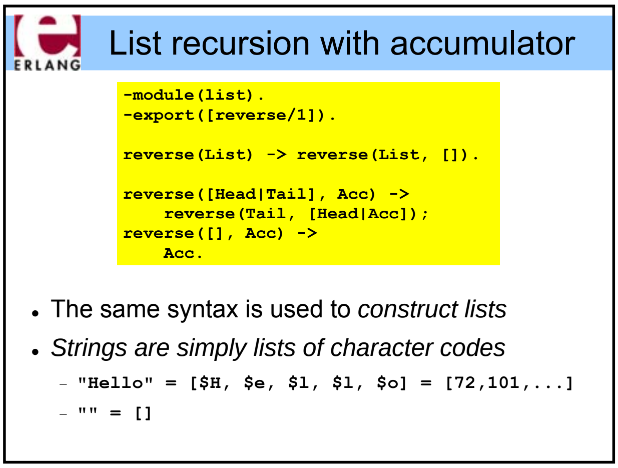
- The *arity is part of the function name:* `fac/1≠fac/2`
- Non-exported functions are local to the module
- Function definitions cannot be nested (as in C)
- Last call optimization: the stack does not grow if the result is the value of another function call



Recursion over lists

```
-module(list).
-export([last/1]).

last([Element]) -> Element;
last([_|Rest]) -> last(Rest).
```

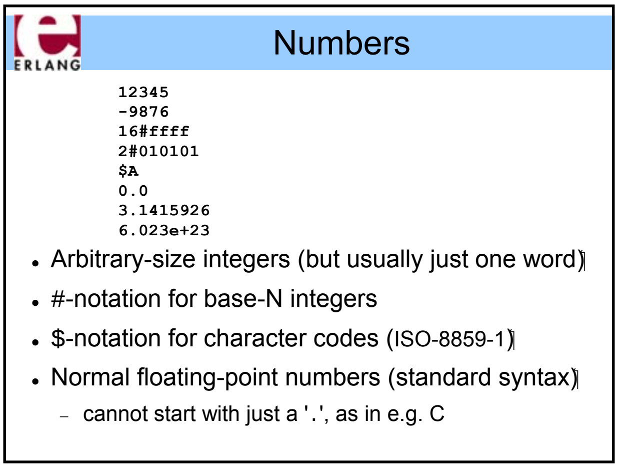
- Pattern matching selects components of the data
- "_" is a "don't care"-pattern (not a variable)
- "`[Head|Tail]`" is the syntax for a single list cell
- "`[]`" is the empty list (often called "nil")
- "`[X,Y,Z]`" is a list with exactly three elements
- "`[X,Y,Z|Tail]`" has three or more elements



List recursion with accumulator

```
-module(list).
-export([reverse/1]).

reverse(List) -> reverse(List, []).

reverse([Head|Tail], Acc) ->
     reverse(Tail, [Head|Acc]);
reverse([], Acc) ->
     Acc.
```

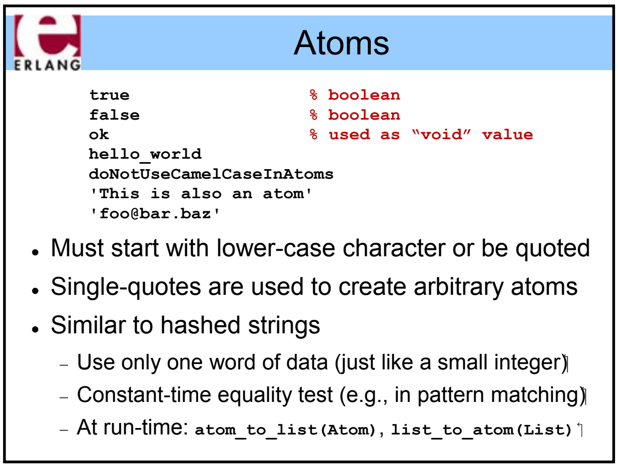
- The same syntax is used to *construct lists*
- *Strings are simply lists of character codes*
  - `"Hello" = [$H, $e, $l, $l, $o] = [72,101,...]`
  - `"" = []`



Numbers

```
12345
-9876
16#ffff
2#010101
$A
0.0
3.1415926
6.023e+23
```

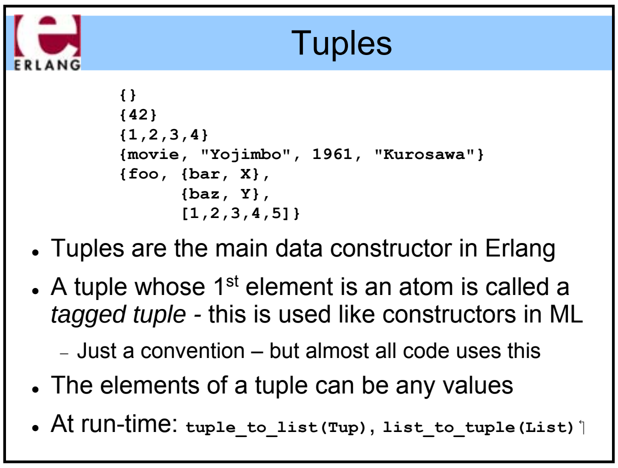
- Arbitrary-size integers (but usually just one word)
- #-notation for base-N integers
- $-notation for character codes (ISO-8859-1)
- Normal floating-point numbers (standard syntax)
  - cannot start with just a '.', as in e.g. C



Atoms

```
true                      % boolean
false                     % boolean
ok                        % used as "void" value
hello_world
doNotUseCamelCaseInAtoms
'This is also an atom'
'foo@bar.baz'
```

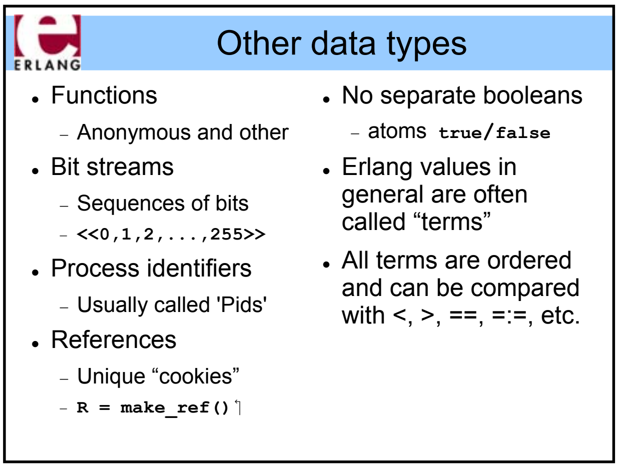
- Must start with lower-case character or be quoted
- Single-quotes are used to create arbitrary atoms
- Similar to hashed strings
  - Use only one word of data (just like a small integer)
  - Constant-time equality test (e.g., in pattern matching)
  - At run-time: `atom_to_list(Atom)`, `list_to_atom(List)`



Tuples

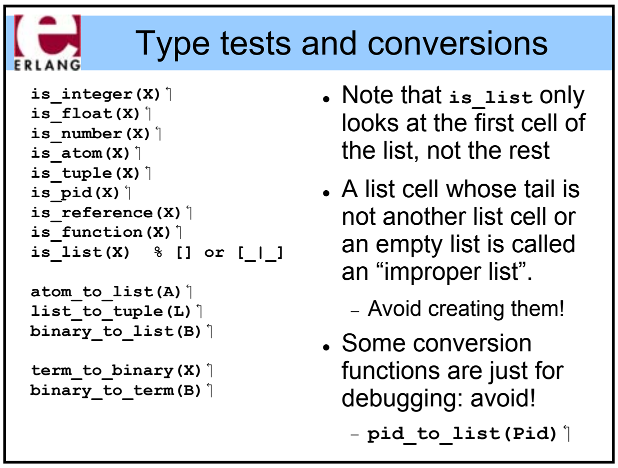
```
{}
{42}
{1,2,3,4}
{movie, "Yojimbo", 1961, "Kurosawa"}
{foo, {bar, X},
      {baz, Y},
      [1,2,3,4,5]}
```

- Tuples are the main data constructor in Erlang
- A tuple whose 1st element is an atom is called a *tagged tuple* - this is used like constructors in ML
  - Just a convention – but almost all code uses this
- The elements of a tuple can be any values
- At run-time: `tuple_to_list(Tup)`, `list_to_tuple(List)`



Other data types

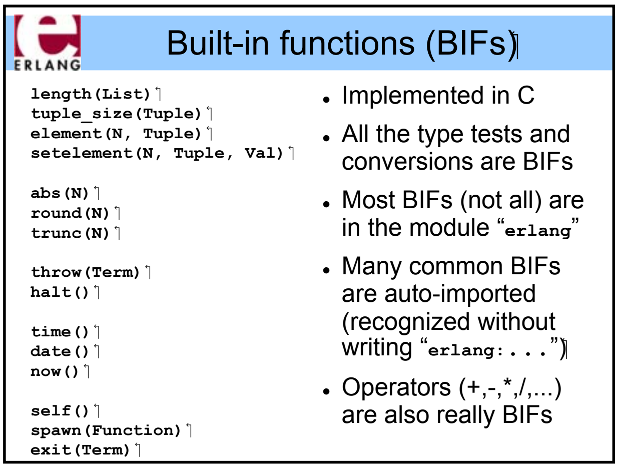
- Functions
  - Anonymous and other
- Bit streams
  - Sequences of bits
  - `<<0,1,2,...,255>>`
- Process identifiers
  - Usually called 'Pids'
- References
  - Unique "cookies"
  - `R = make_ref()`
- No separate booleans
  - atoms `true/false`
- Erlang values in general are often called "terms"
- All terms are ordered and can be compared with <, >, ==, =:=, etc.



Type tests and conversions

```
is_integer(X)
is_float(X)
is_number(X)
is_atom(X)
is_tuple(X)
is_pid(X)
is_reference(X)
is_function(X)
is_list(X)   % [] or [_|_]

atom_to_list(A)
list_to_tuple(L)
binary_to_list(B)

term_to_binary(X)
binary_to_term(B)
```

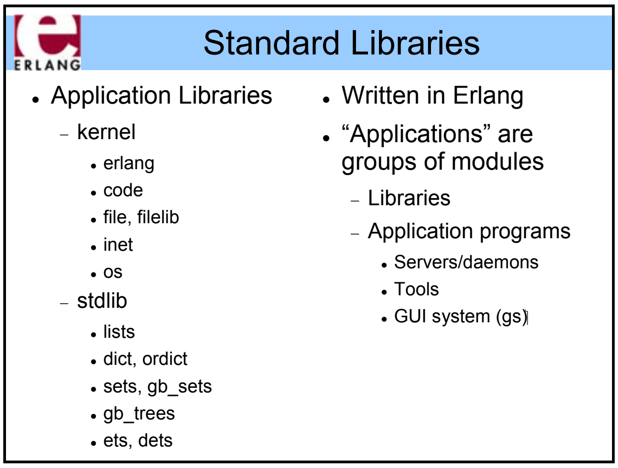
- Note that `is_list` only looks at the first cell of the list, not the rest
- A list cell whose tail is not another list cell or an empty list is called an "improper list".
  - Avoid creating them!
- Some conversion functions are just for debugging: avoid!
  - `pid_to_list(Pid)`



Built-in functions (BIFs)

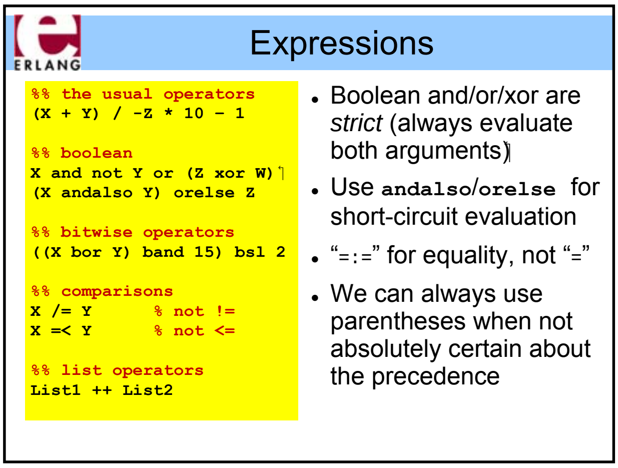
```
length(List)
tuple_size(Tuple)
element(N, Tuple)
setelement(N, Tuple, Val)

abs(N)
round(N)
trunc(N)

throw(Term)
halt()

time()
date()
now()

self()
spawn(Function)
exit(Term)
```

- Implemented in C
- All the type tests and conversions are BIFs
- Most BIFs (not all) are in the module "`erlang`"
- Many common BIFs are auto-imported (recognized without writing "`erlang:...`")
- Operators (+,-,*,/,...) are also really BIFs



Standard Libraries

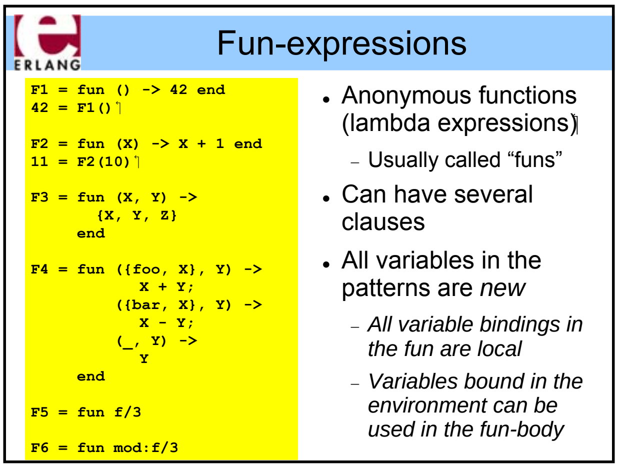
- Application Libraries
  - kernel
    - erlang
    - code
    - file, filelib
    - inet
    - os
  - stdlib
    - lists
    - dict, ordict
    - sets, gb_sets
    - gb_trees
    - ets, dets
- Written in Erlang
- “Applications” are groups of modules
  - Libraries
  - Application programs
    - Servers/daemons
    - Tools
    - GUI system (gs)



Expressions

```
%% the usual operators
(X + Y) / -Z * 10 – 1

%% boolean
X and not Y or (Z xor W)
(X andalso Y) orelse Z

%% bitwise operators
((X bor Y) band 15) bsl 2

%% comparisons
X /= Y        % not !=
X =< Y        % not <=

%% list operators
List1 ++ List2
```

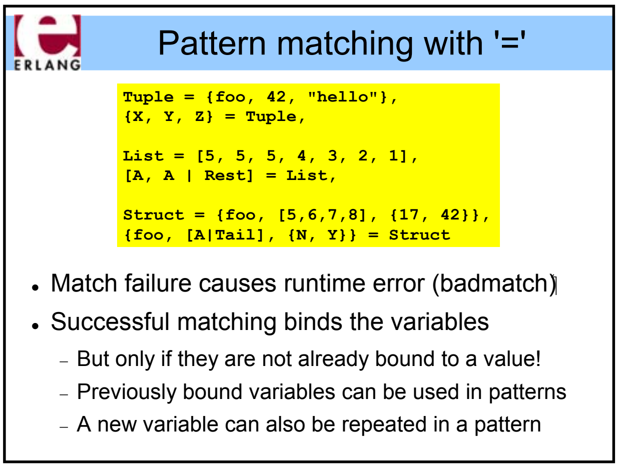
- Boolean and/or/xor are *strict* (always evaluate both arguments)
- Use `andalso`/`orelse` for short-circuit evaluation
- “`=:=`” for equality, not “`=`”
- We can always use parentheses when not absolutely certain about the precedence



Fun-expressions

```
F1 = fun () -> 42 end
42 = F1()

F2 = fun (X) -> X + 1 end
11 = F2(10)

F3 = fun (X, Y) ->
       {X, Y, Z}
     end

F4 = fun ({foo, X}, Y) ->
           X + Y;
         ({bar, X}, Y) ->
           X - Y;
         (_, Y) ->
           Y
     end

F5 = fun f/3

F6 = fun mod:f/3
```

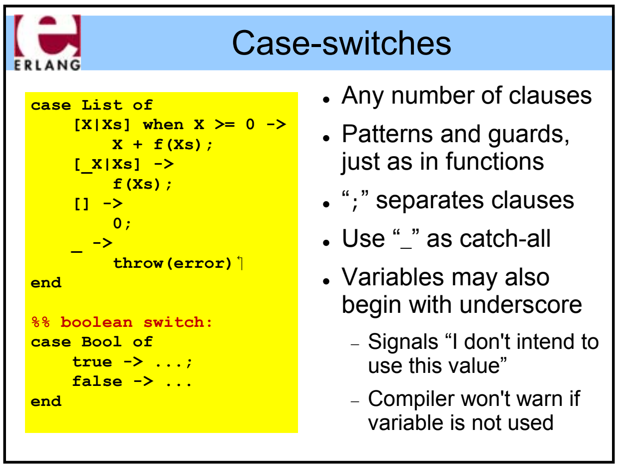
- Anonymous functions (lambda expressions)
  - Usually called “funs”
- Can have several clauses
- All variables in the patterns are *new*
  - *All variable bindings in the fun are local*
  - *Variables bound in the environment can be used in the fun-body*



Pattern matching with '='

```
Tuple = {foo, 42, "hello"},
{X, Y, Z} = Tuple,

List = [5, 5, 5, 4, 3, 2, 1],
[A, A | Rest] = List,

Struct = {foo, [5,6,7,8], {17, 42}},
{foo, [A|Tail], {N, Y}} = Struct
```

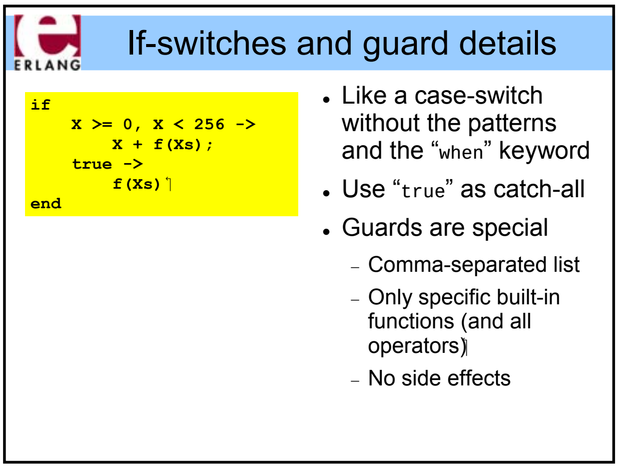
- Match failure causes runtime error (badmatch)
- Successful matching binds the variables
  - But only if they are not already bound to a value!
  - Previously bound variables can be used in patterns
  - A new variable can also be repeated in a pattern



Case-switches

```
case List of
    [X|Xs] when X >= 0 ->
        X + f(Xs);
    [_X|Xs] ->
        f(Xs);
    [] ->
        0;
    _ ->
        throw(error)
end

%% boolean switch:
case Bool of
    true -> ...;
    false -> ...
end
```

- Any number of clauses
- Patterns and guards, just as in functions
- “;” separates clauses
- Use “_” as catch-all
- Variables may also begin with underscore
  - Signals “I don't intend to use this value”
  - Compiler won't warn if variable is not used



If-switches and guard details

```
if
    X >= 0, X < 256 ->
        X + f(Xs);
    true ->
        f(Xs)
end
```

- Like a case-switch without the patterns and the “`when`” keyword
- Use “`true`” as catch-all
- Guards are special
  - Comma-separated list
  - Only specific built-in functions (and all operators)
  - No side effects

List comprehensions

```
%% map
[f(X)  || X <- List]

%% filter
[X || X <- Xs, X > 0]


%% quicksort example
qsort([P|Xs]) ->
  qsort([X || X <- Xs,
              X < P])
  ++ [P]  % pivot element
  ++ qsort([X || X <- Xs,
                 X >= P]);
qsort([]) ->
  [].
```

- Left of the "`||`" is an *expression template*
- "`Pattern <- List`" is a *generator*
  - Elements are picked from the list in order
- The other expressions are *boolean filters*
- If there are multiple generators, you get all combinations of values

Catching exceptions

```
try
    lookup(X)
catch
    not_found ->
        use_default(X);
    exit:Term ->
        handle_exit(Term)
end

%% with 'of' and 'after'
try lookup(X, File) of
    Y when Y > 0 -> f(Y);
    Y -> g(Y)
catch
    ...
after
    close_file(File)
end
```

- Three classes of exceptions
  - `throw`: user-defined
  - `error`: runtime errors
  - `exit`: end process
  - Only catch `throw` exceptions, normally (implicit if left out)
- Re-thrown if no catch-clause matches
- "`after`" part is always run (side effects only)

Old-style exception handling

```
Val = (catch lookup(X)),

case Val of
    not_found ->
        %% probably thrown
        use_default(X);
    {'EXIT', Term} ->
        handle_exit(Term);
    _ ->
        Val
end
```

- "`catch Expr`"
  - Value of "`Expr`" if no exception
  - Value `X` of "`throw(X)`" for a `throw`-exception
  - "`{'EXIT',Term}`" for other exceptions
- Hard to tell what happened (not safe)
- Mixes up errors/exits
- In lots of old code

Record syntax

```
-record(foo, {a=0, b}).

{foo, 0, 1} = #foo{b=1}

R = #foo{}
{foo, 0, undefined} = R

{foo, 0, 2} = R#foo{b=2}

{foo, 2, 1} = R#foo{b=1,
                    a=2}

0 = R#foo.a
undefined = R#foo.b

f(#foo{b=undefined}) -> 1;
f(#foo{a=A, b=B})
  when B > 0 -> A + B;
f(#foo{}) -> 0.
```

- Records are just a syntax for working with tagged tuples
- You don't have to remember element order and tuple size
- Good for internal work within a module
- Not so good in public interfaces (users must have same definition!)

Preprocessor

```
-include("defs.hrl").

-ifndef(PI).
-define(PI, 3.1415926).
-endif.

area(R) -> ?PI * (R*R).


-define(foo(X), {foo,X+1}).

{foo,2} = ?foo(1)


%% pre-defined macros
?MODULE
?LINE
```

- C-style token-level preprocessor
  - Runs after tokenizing, but before parsing
- Record definitions often put in header files, to be included
- Use macros mainly for constants
- Use functions instead of macros if you can (compiler can inline)

Type declarations

- Erlang has a notation for declaring types out of the "built-in" ones

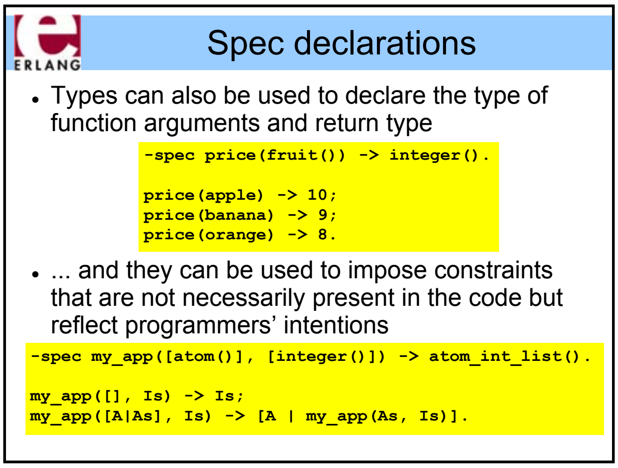
```
-type fruit() :: 'apple' | 'banana' | 'orange'.
```

```
-type fruit_list() :: [fruit()].
```

```
-type atom_int_list() :: [atom() | integer()].
```

- These types can then be used to declare the type of record fields

```
-record(my_rec, {a = 0  :: integer(),
                 b      :: fruit(),
                 c = [] :: atom_int_list()}).
```



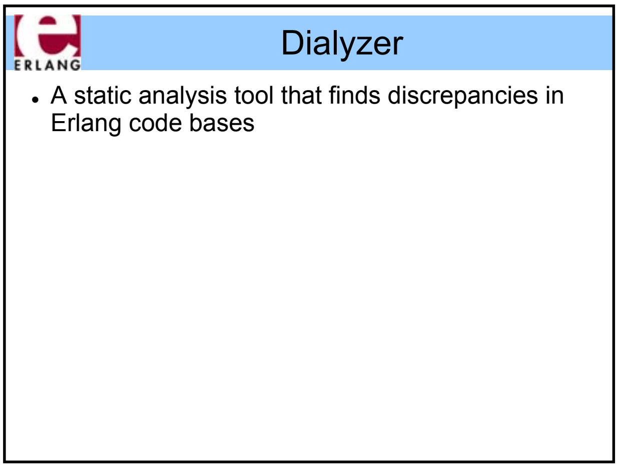
Spec declarations

- Types can also be used to declare the type of function arguments and return type

```
-spec price(fruit()) -> integer().

price(apple) -> 10;
price(banana) -> 9;
price(orange) -> 8.
```

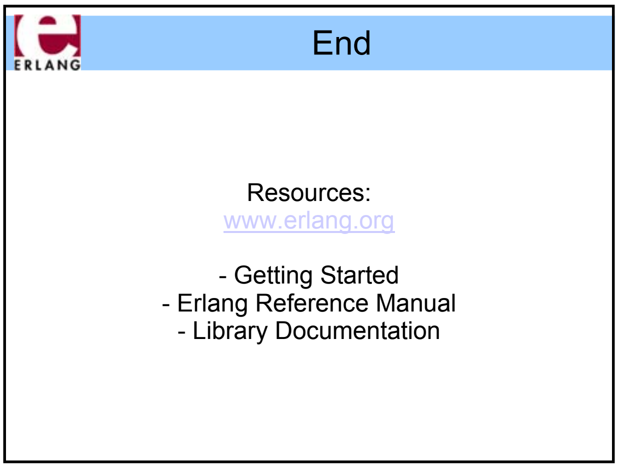
- ... and they can be used to impose constraints that are not necessarily present in the code but reflect programmers’ intentions

```
-spec my_app([atom()], [integer()]) -> atom_int_list().

my_app([], Is) -> Is;
my_app([A|As], Is) -> [A | my_app(As, Is)].
```



Dialyzer

- A static analysis tool that finds discrepancies in Erlang code bases



End

Resources:
www.erlang.org

- Getting Started
- Erlang Reference Manual
- Library Documentation