Elixir's Set-Theoretic Type System

Robert Ellen

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Summary

Elixir

Elixir

The Erlang Ecosystem

What is the Erlang Ecosystem?

A group of languages, libraries, frameworks, and applications that are implemented on top of the Erlang virtual machine, the BEAM.

Languages include:

...plus dozens more

What is the Erlang Ecosystem?

Libraries and frameworks include:

OTP

What is the Erlang Ecosystem?

Built around a shared value in:

- massive concurrency
- fault-tolerance
- simplicity
- acknowledging the errors will occur so let's deal with them
  - "Let it crash"–have a plan to restart sub-systems when they crash

A brief history of Erlang

A brief history of Erlang

covered in my 2013 talk, but tonight...

A brief history of Erlang

A brief history of Erlang

- developed in the mid 1980s at Ericsson
- to run on next generation telephone switches
  - concurrent, fault-tolerant, distributed, soft real-time
  - strong, dynamic typing, impure, functional, simple
  - reports of 1200k LOC and “nine nines” of uptime on the AXD301 switch
  - reports of market penetration of > 50% in mobile telephony switches
- solved web-scale in the '80s

The BEAM and OTP

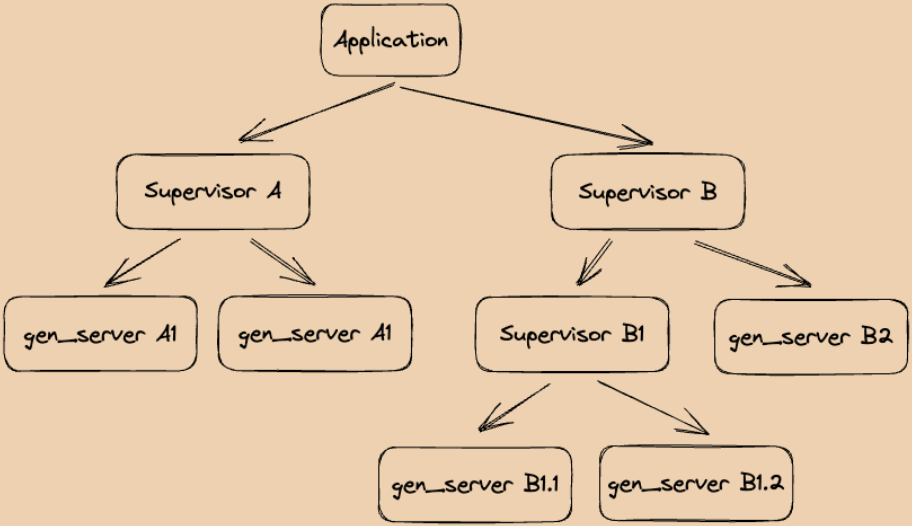
The BEAM

- Erlang's virtual machine / runtime system
- lightweight processes, SMP
- multi-generational, per-process garbage collector
- asynchronous, location-transparent, message-passing IPC
- hot-code-loading
- powerful REPL and introspection tools
- new JIT compiler (BEAM bytecode to machine code)

The OTP libraries

- Erlang's “standard library”
- dozens of modules providing various typical stdlib stuff
- core of which are for supervision trees
  - `gen_server` - actors / workers
  - supervisors - handling starting/stopping/restarting `gen_servers`

supervision trees



Elixir

There will be some comparing and contrasting of Gleam with Elixir...

Brief history of Elixir

- created by José Valim starting in 2012
- inspired by Erlang, Ruby, and, to a lesser extent, Lisp
- like Erlang, the language is quite stable

Features of Elixir

- Ruby-like syntax while retaining most of Erlang's semantics
  - ..., immutable data, HoF, side-effects anywhere, dynamically-typed, ...
- interoperate with Erlang
- hygienic macros
- highly ergonomic build tool: `mix`
- modern package manager: `hex`
- excellent unit test tool: exunit
- opinionated formatter
- drops strict SSA in favour of rebinding

Typing BEAM languages

Marlow & Wadler - 1997

“We can stop waiting for functional languages to be used in practice–that day is here!”

- threw away Hindley-Milner: $U = V$ – this would not work with existing Erlang codebases
- opted for strictly more general “semantic sub-typing” instead: $U \subseteq V$
- (Aiken & Wimmers - 1993)

eqWAlizer

Developed by Meta for WhatsApp

Static analysis tools

- rely on the Erlang Typespec notation - not checked by compiler
- dialyzer - success-typing - Linhahl & Sagonas, 2006
- gradualizer - gradual set-theoretic-inspired typing

Typed BEAM languages with alternate semantics

- Hamler - PureScript for the BEAM
- Caramel - ML for the BEAM
- Gleam - Rust/Ocaml/Elm inspired - HM type system
  - see my May 2024 talk
- ...

Elixir's Set-Theoretic Type System

Goal

- works on existing Elixir code-bases
- need range of techniques to give system a chance of being adopted

Features of the type system

- semantic sub-typing hence set-theoretic
- polymorphic with local type inference
  - type variables
  - requires some type annotations–but not everywhere

Semantic sub-typing

- establish sub-typing relationships between types based on the semantic meaning of values of the types
- semantic meaning derived from treating types as sets, values as set members
- set operations on types: union, intersection, and negation
- in comparison to Hindley-Milner, relax $U = V$ to $U \subseteq V$
- strictly more general - an extension to HM
- Frish et. al. referencing Aiken & Wimmers (also ref. by Marlow & Wadler)
- good idea because dynamically-typed languages variables can hold different types at run-time: hence union-ing

Polymorphic with local type inference

- type variables: `a`, `b` - no parentheses
- local type inference
  - functions must have type annotations
  - types are inferred for arguments and return types

Polymorphic with local type inference

```
$ (list(a), a → b) → list(b)
def map([], _), do: []
def map([x | xs], f), do:  [f.(x) | map(xs, f)]

x = map([1, 2, 3], &double/1)
# type system infers type of double and x
```

Guards and pattern-matching

- Elixir has rich run-time testing of types
- the type system can type captured variables and variables in guards

```
def elem_at([x | rest] = xs, pos) when is_integer(pos) do ...
```

Guards and pattern-matching

- “type narrowing” can check exhaustiveness of case expressions
- type system is conservative: case branches must handle `xs` being any map or list

```
def elem_at(xs, pos) when is_map(xs) or is_list(x) do
  case xs do
    %{} → # get for map
    [] → # get for list
    _ → # redundant
  end
end
```

Maps as “records” and “dictionaries”

- maps can represent records, dictionaries, and structs

```
ashley = %{name: "Ashley", age: 42}
# ashley :: %{:name => binary(), :age => integer()}

words = "The Elixir Type System ..."
word_count = wc(words) # :: %{optional(binary()) => integer()}
word_count["Elixir"] # 42

defstruct [:id , name: "", age: 0]
# %{
#   :__struct__ => :"User",
#   :id => term(),
#   :name => binary(),
#   :age => integer()
# }
```

Maps as “records” and “dictionaries”

- the type system treats maps as open or closed
  - open means there are potentially unknown keys
- strict or dynamic access changes type inference

```
user.first_name # user :: %{:first_name => term(), ...}

middle = person["middle_name"]
# person :: %{optional("middle_name") => term(), ...} => %{...}
# middle :: binary() or nil

ashley = %{name: "Ashley", age: 42}
# ashley :: %{:name => binary(), :age => integer()}
```

Maps as “records” and “dictionaries”

- sub-typing maps feels like structural sub-typing...

```
ashley = %{name: "Ashley", age: 42}
# ashley :: %{:name => binary(), :age => integer()}

ashley_at_school = %{name: "Ashley", age: 42, gpa: 6.75}
# ashley_at_school :: %{:name => binary(),
#                       :age => integer(),
#                       :gpa => float()}

def enroll(%{name: _, age: _} = person) do ...
```

- the type system innovates semantic sub-typing to handle maps
  - Castagna 2023

Gradual typing with `dynamic()`

Gradually introducing the system

- don't discount the chance of a deal-breaker in prod code taking them back to the drawing board

References

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Thank you

I'll post slides soon.