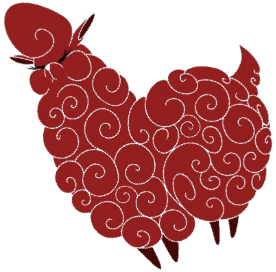
A Lisp for microcontrollers

Joel Svensson

Chalmers FP-Talk Dec 8 2023



LBM (LispBM)

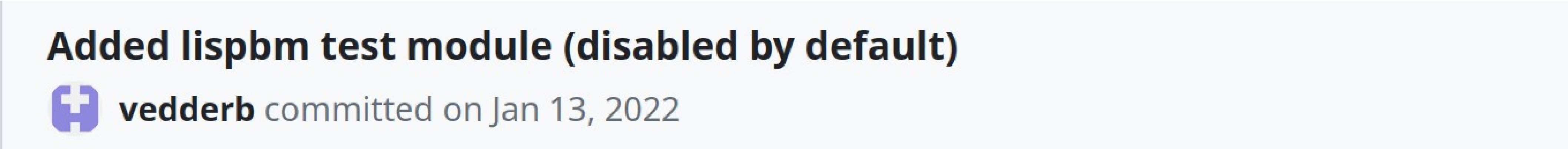
- A lisp dialect for microcontrollers.
  - 32bit architectures.
  - 128KB of ram or more. Maybe a bit less even.
  - Flash storage.
  - Usually no cache between CPU and RAM.
  - Sometimes cache/accelerator between CPU and flash.
- Intended to run concurrently with a C application.

DEMO

Five years of fun, so far.

- How it began in 2018
  - SICP videos on youtube.
  - Microcontrollers at work.

- When it “took off”
  - 2022-12-09: VESC firmware version 6.0.
  - Thank you Benjamin Vedder.



Added lispbm test module (disabled by default)

vedderb committed on Jan 13, 2022

Features

- GC.
  - Stack based MS.
  - Pointer reversal MS.
- Call-CC.
- QQ
  - Quasiquotation in Lisp – Bawden.
- Macros.
- Different modes of reading.

- Message passing.
- Concurrency.
- Pattern matching.
- Byte arrays.
- Flash storage.
  - Programs and data.
- Profiler.

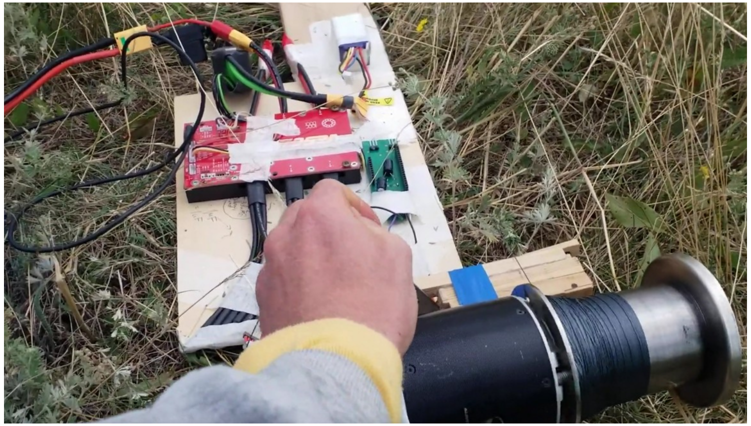
Retired features

- Namespaces.
- Partial Application.
- Some other array types.
- Wait-for flags.
- Cooperative scheduling.

Goals

- Small and somewhat efficient language.
- Sandboxed evaluation of code.
  - Add scripting capabilities to application X.
  - Buggy applications should not crash X.

Luke F: https://www.youtube.com/watch?v=QNGDMCOsarM



Kites for future: https://www.youtube.com/watch?v=pU08gItGpAs

Alexander Krasnov: https://github.com/aka13-404/VSETT-LISP

https://github.com/leocelente/vesc-rs485-lispbm

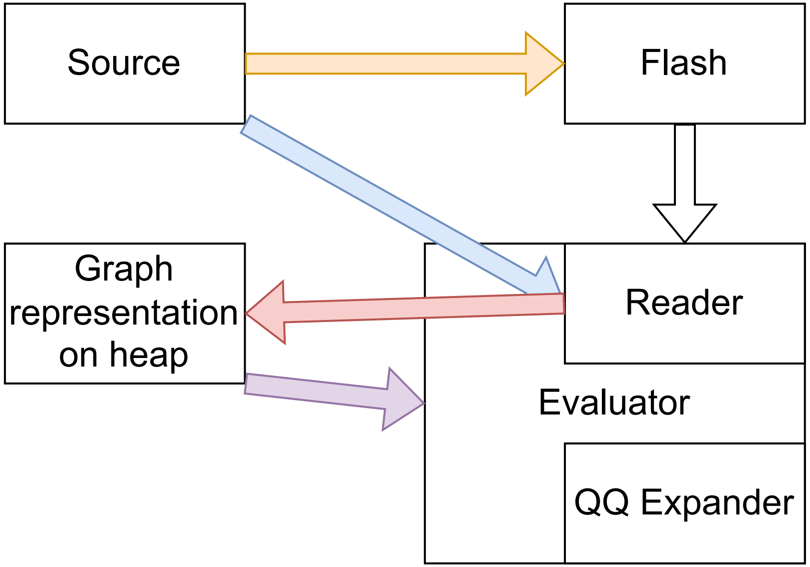
https://github.com/tonymillion/VescNinebotDash

https://github.com/m365fw/vesc_m365_dash

lispBM language support

Rasmus Söderhielm | 20 installs | ★★★★★ (0) | Free

Overview


Source
Flash
Graph representation on heap
Reader
Evaluator
QQ Expander

Overview

```
  208 env.c
 4370 eval_cps.c
  147 extensions.c
 1319 fundamental.c
 1344 heap.c
  424 lbm_channel.c
  297 lbm_c_interop.c
   52 lbm_custom_type.c
   32 lbm_flags.c
  696 lbm_flat_value.c
  457 lbm_memory.c
  118 lbm_prof.c
   79 lbm_variables.c
   51 lispbm.c
  421 print.c
  118 stack.c
  493 symrepr.c
  529 tokpar.c
11155 total
```

Evaluation of expressions

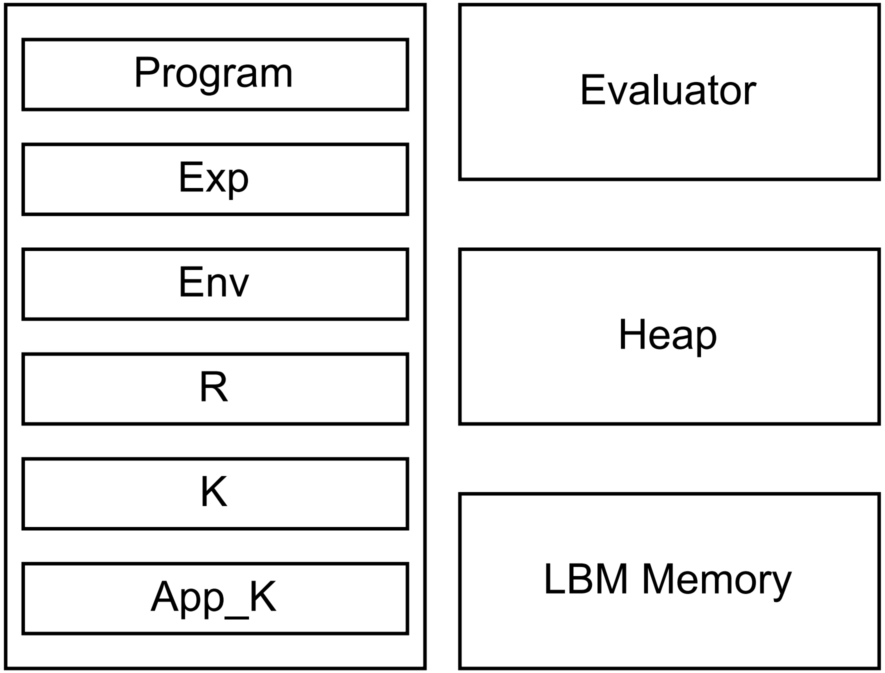
```
data Exp = Num Int
     | Add Exp Exp

type Cont = Int -> Int

myExp = Add (Num 2) (Num 3)
myExp2 = Add myExp myExp

eval :: Cont -> Exp -> Int
eval c (Num a) = c a
eval c (Add a b) =
     eval (\v ->
          eval (\v1 -> c (v + v1)) b) a
```

Evaluation of expressions

```
*Main> eval id
myExp
5
*Main> eval id
myExp2
10
```

```
myExp = Add (Num 2) (Num
3)
myExp2 = Add myExp myExp
```

LBM Evaluator Architecture



Program

Exp

Env

R

K

App_K

Evaluator

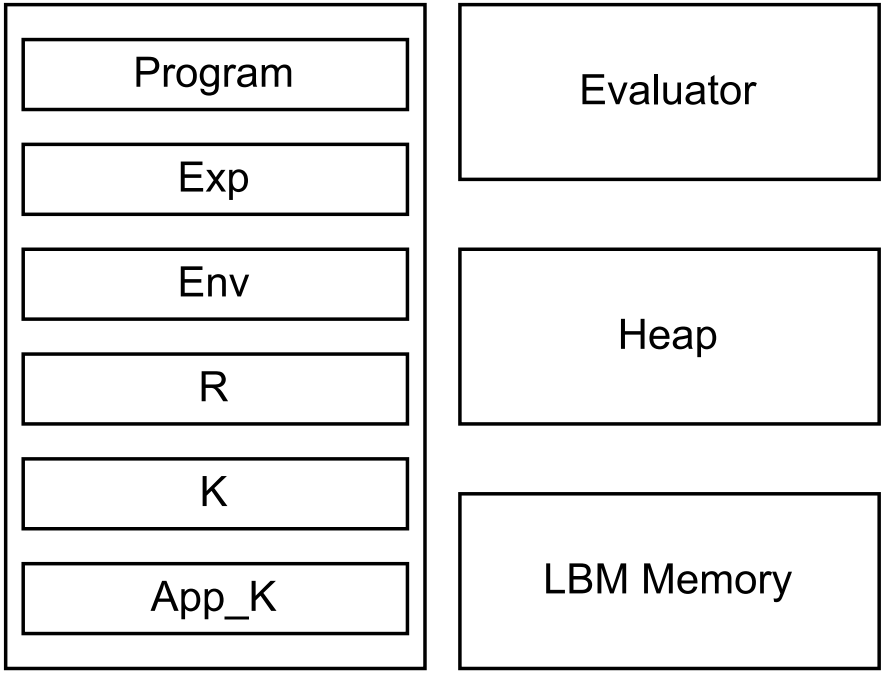
Heap

LBM Memory

Eval loop

```
while (true) {
  if (App_K) {
     apply_cont();
  } else {
     /* pattern match on Exp
*/
  }
}
```

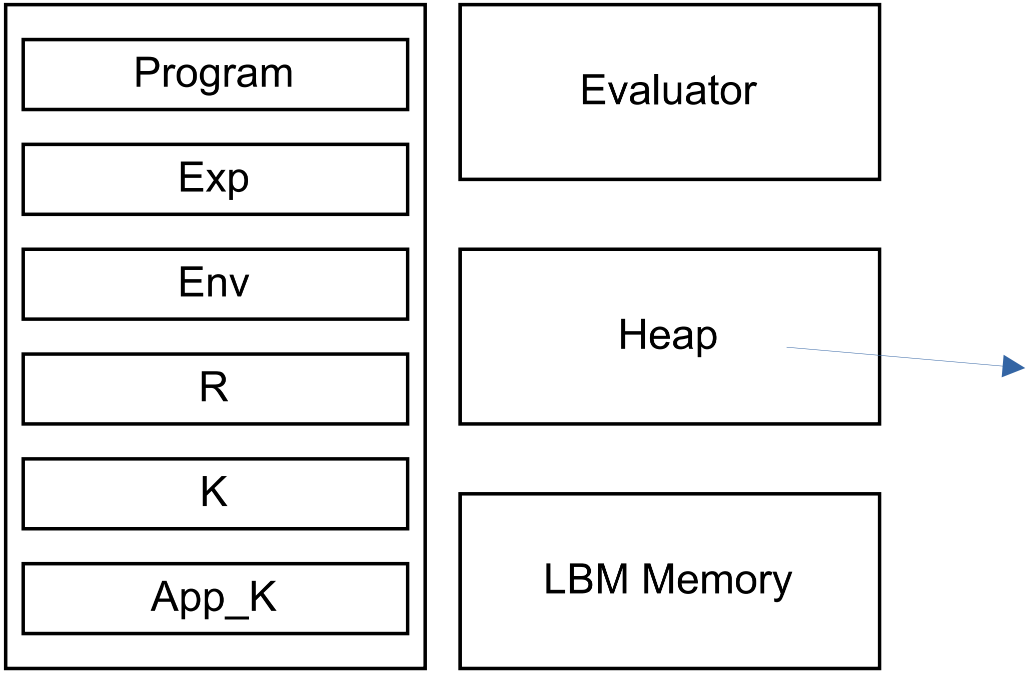
LBM Evaluator Architecture



Evaluate this!

```
(define a 10)
(define b 20)
(+ a b)
```

LBM Evaluator Architecture



Program

Exp

Env

R

K

App_K

Evaluator

Heap

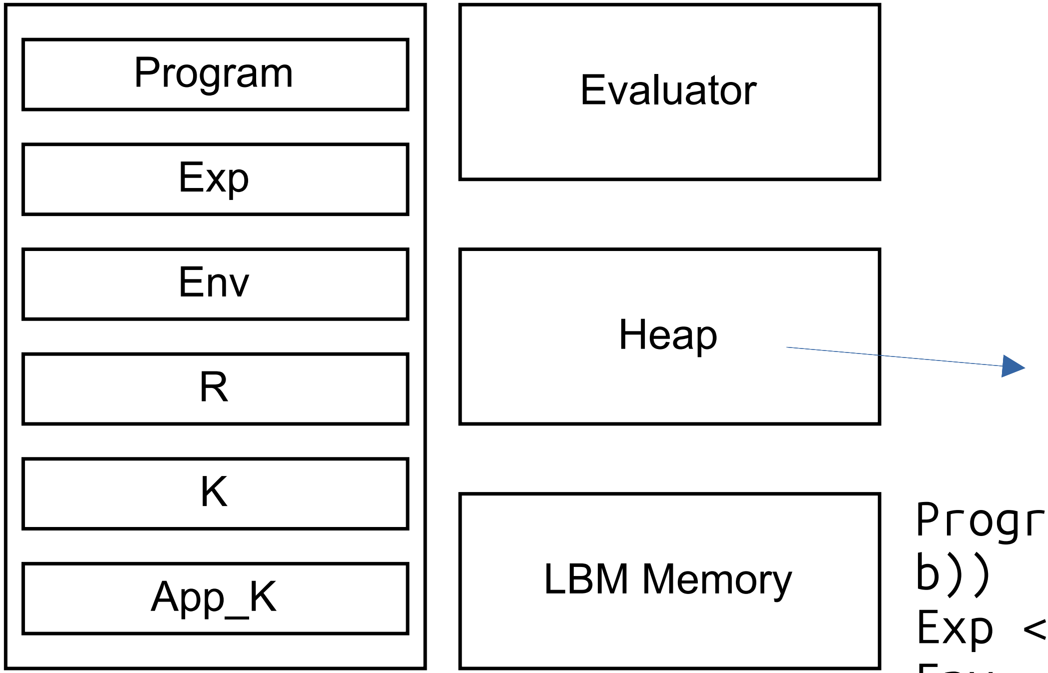
LBM Memory

Evaluate this!

```
(define a 10)
(define b 20)
(+ a b)
```

```
((define a 10) (define b 20) (+ a
b))
```

LBM Evaluator Architecture



Program

Exp

Env

R

K

App_K

Evaluator

Heap

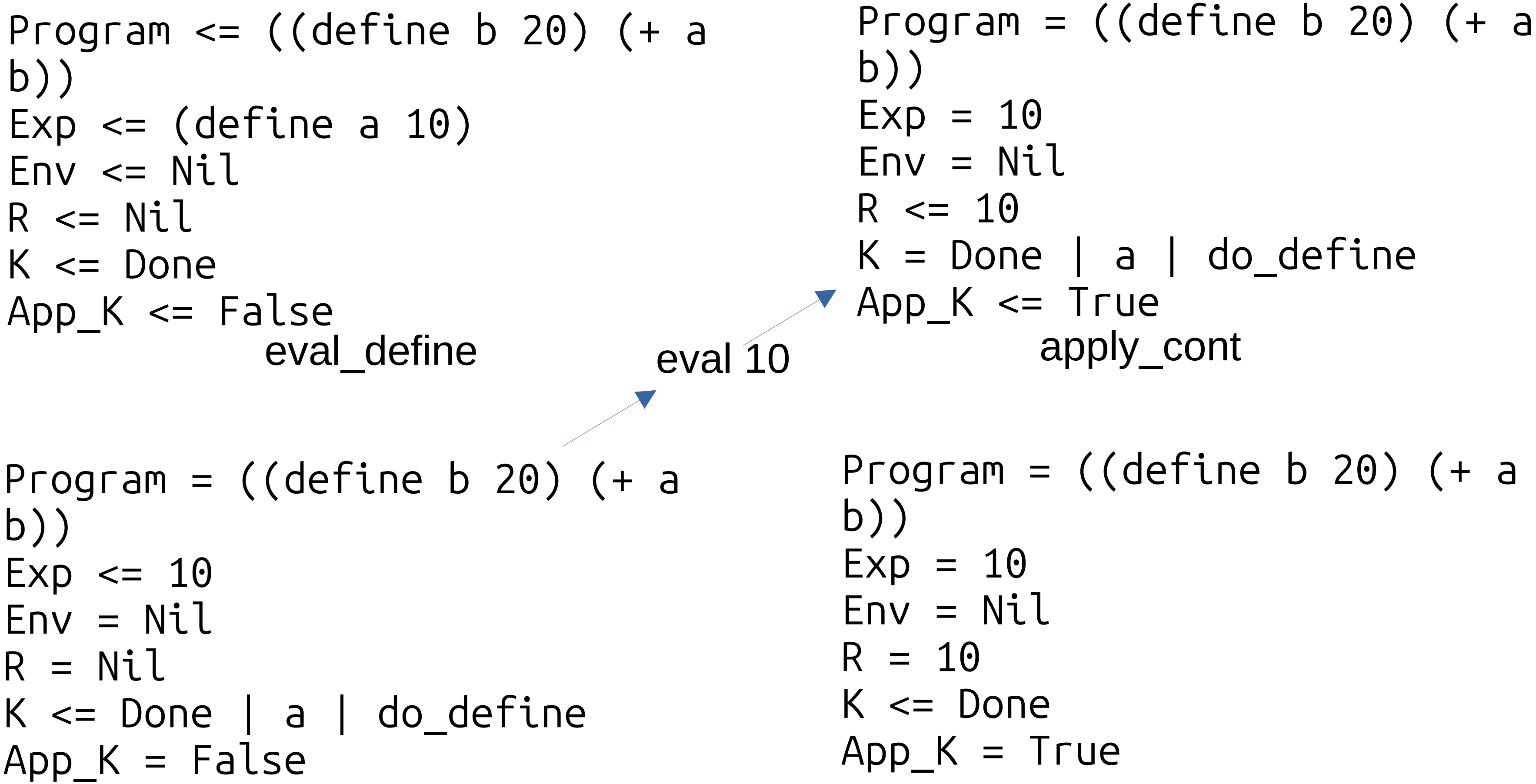
LBM Memory

Evaluate this!

```
(define a 10)
(define b 20)
(+ a b)
```

```
((define a 10) (define b 20) (+ a
b))
```

```
Program <= ((define b 20) (+ a
b))
Exp <= (define a 10)
Env <= Nil
R <= Nil
K <= Done
App_K <= False
```



```
Program <= ((define b 20) (+ a
b))
Exp <= (define a 10)
Env <= Nil
R <= Nil
K <= Done
App_K <= False
```

eval_define

```
Program = ((define b 20) (+ a
b))
Exp <= 10
Env = Nil
R = Nil
K <= Done | a | do_define
App_K = False
```

eval 10

```
Program = ((define b 20) (+ a
b))
Exp = 10
Env = Nil
R <= 10
K = Done | a | do_define
App_K <= True
```

apply_cont

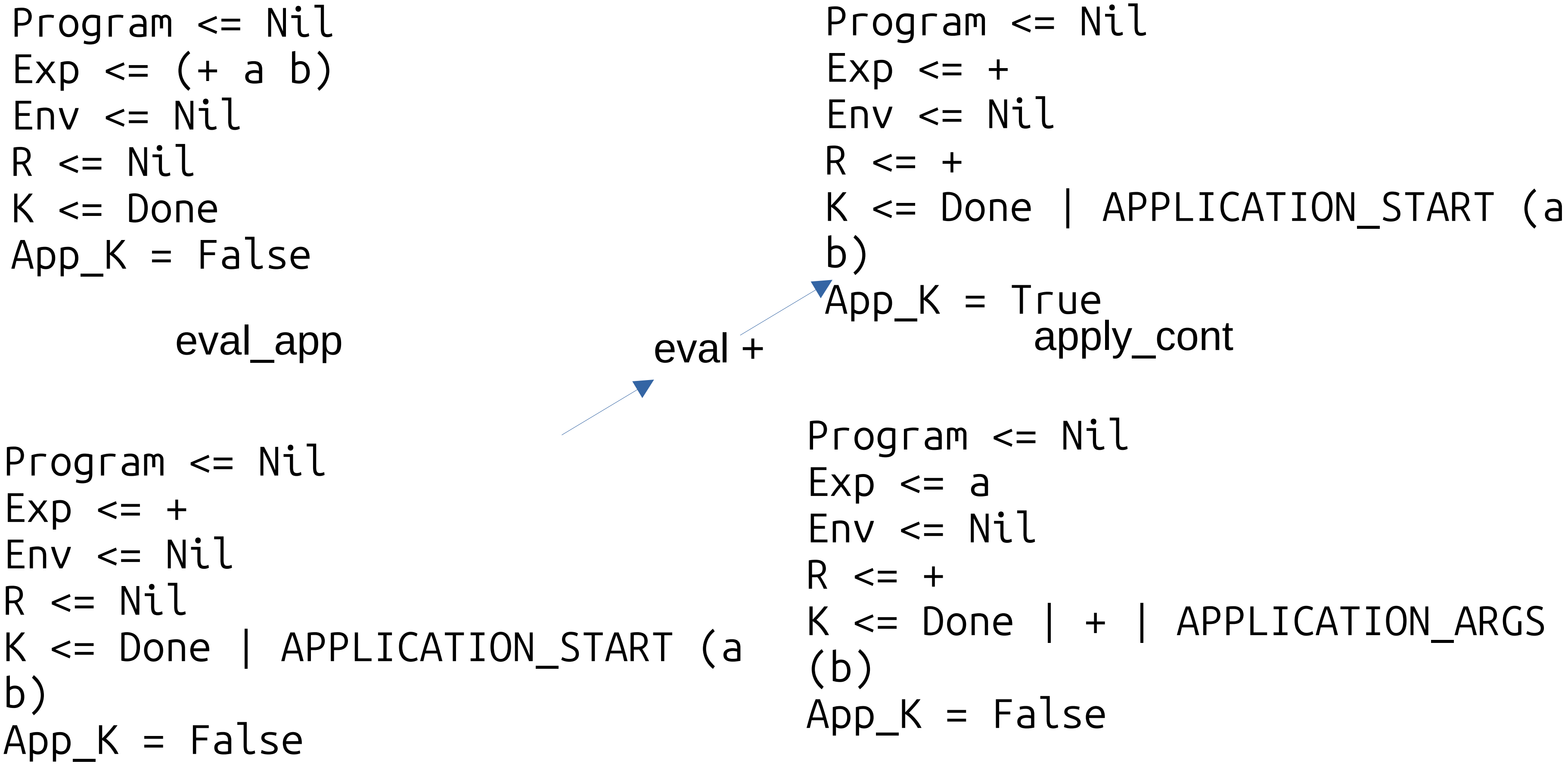
```
Program = ((define b 20) (+ a
b))
Exp = 10
Env = Nil
R = 10
K <= Done
App_K = True
```

```
Program = ((define b 20) (+ a
b))
Exp = 10
Env = Nil
R = 10
K <= Done
App_K = True
```

apply_cont

```
Program <= ((+ a b))
Exp <= (define b 20)
Env <= Nil
R <= Nil
K <= Done
App_K <= False
```

Repeat earlier steps



```
Program <= Nil
Exp <= (+ a b)
Env <= Nil
R <= Nil
K <= Done
App_K = False
```

eval_app

```
Program <= Nil
Exp <= +
Env <= Nil
R <= Nil
K <= Done | APPLICATION_START (a
b)
App_K = False
```

eval +

```
Program <= Nil
Exp <= +
Env <= Nil
R <= +
K <= Done | APPLICATION_START (a
b)
App_K = True
```

apply_cont

```
Program <= Nil
Exp <= a
Env <= Nil
R <= +
K <= Done | + | APPLICATION_ARGS
(b)
App_K = False
```

```
Program <= Nil
Exp <= a
Env <= Nil
R <= +
K <= Done | + | APPLICATION_ARGS
(b)
App_K = False
```

lookup a

```
Program <= Nil
Exp <= a
Env <= Nil
R <= 10
K <= Done | + | APPLICATION_ARGS
(b)
App_K = True
```

apply_cont

```
Program <= Nil
Exp <= b
Env <= Nil
R <= 10
K <= Done | + | 10 | APPLICATION_ARG
Nil
App_K = False
```

lookup b

```
Program <= Nil
Exp <= b
Env <= Nil
R <= 20
K <= Done | + | 10 APPLICATION_ARGS
Nil
App_K = True
```

```
Program <= Nil
Exp <= b
Env <= Nil
R <= 30
K <= Done
App_K = True
```

```
// (define sym exp)
static void eval_define(eval_context_t *ctx) {
  lbm_value args = get_cdr(ctx->curr_exp);
  lbm_value key, rest_args;
  get_car_and_cdr(args, &key, &rest_args);
  lbm_value val_exp, rest_val;
  get_car_and_cdr(rest_args, &val_exp, &rest_val);
  lbm_uint *sptr = stack_reserve(ctx, 2);
  if (lbm_is_symbol(key) && lbm_is_symbol_nil(rest_val)) {
    lbm_uint sym_val = lbm_dec_sym(key);
    sptr[0] = key;
    if (sym_val >= RUNTIME_SYMBOLS_START) {
      sptr[1] = SET_GLOBAL_ENV;
      if (ctx->flags & EVAL_CPS_CONTEXT_FLAG_CONST) {
        stack_push(&ctx->K, MOVE_VAL_TO_FLASH_DISPATCH);
      }
      ctx->curr_exp = val_exp;
      return;
    }
  }
  error_at_ctx(ENC_SYM_EERROR, ctx->curr_exp);
```

```
static void cont_set_global_env(eval_context_t *ctx){

  lbm_value key;
  lbm_value val = ctx->r;

  lbm_pop(&ctx->K, &key);
  lbm_value new_env;
  // A key is a symbol and should not need to be remembered.
  WITH_GC(new_env, lbm_env_set(*lbm_get_env_ptr(),key,val));

  *lbm_get_env_ptr() = new_env;
  ctx->r = val;

  ctx->app_cont = true;

  return;
}
```

Pattern match on Exp

```
while (true) {
  if (App_K) {
     apply_cont();
  } else {
     /* pattern match on Exp
*/
  }
}
```

- Symbol
  - Look it up
- (Special-form e_1 … e_n)
  - define, lambda. The built-in syntax essentially
- (x e_1 … e_n) - General application form
  - Closure, Continuation (from call/cc), Fundamental-operation,
  - Extension, something I call an “apply_fun”.
- Anything else

```
static const evaluator_fun
evaluators[] =
  {
   eval_quote,
   eval_define,
   eval_progn,
   eval_lambda,
   eval_if,
   eval_let,
   eval_and,
   eval_or,
   eval_match,
   eval_receive,
   eval_receive_timeout,
   eval_callcc,
   eval_atomic,
   eval_selfevaluating, // macro
   eval_selfevaluating, // cont
   eval_selfevaluating, //
closure
   eval_cond,
   eval_app_cont,
   eval_var,
   eval_setq
```

```
static const apply_fun
fun_table[] =
  {
   apply_setvar,
   apply_read,
   apply_read_program,
   apply_read_eval_program,
   apply_spawn,
   apply_spawn_trap,
   apply_yield,
   apply_wait,
   apply_eval,
   apply_eval_program,
   apply_send,
   apply_ok,
   apply_error,
   apply_map,
   apply_reverse,
   apply_flatten,
   apply_unflatten,
   apply_kill,
   apply_sleep,
  };
```

```
const fundamental_fun fundamental_table[]
=
  {fundamental_add,
   fundamental_sub,
   fundamental_mul,
   fundamental_div,
   fundamental_mod,
   fundamental_eq,
   fundamental_not_eq,
   fundamental_numeq,
   fundamental_num_not_eq,
   fundamental_lt,
   fundamental_gt,
   fundamental_leq,
   fundamental_geq,
   fundamental_not,
   fundamental_gc,
   fundamental_self,
   fundamental_set_mailbox_size,
   fundamental_cons,
   fundamental_car,
   fundamental_cdr
```

```
static const cont_fun
continuations[NUM_CONTINUATIONS] =
  { advance_ctx,  // CONT_DONE
    cont_set_global_env,
    cont_bind_to_key_rest,
    cont_if,
    cont_progn_rest,
    cont_application_args,
    cont_and,
    cont_or,
    cont_wait,
    cont_match,
    cont_application_start,
    cont_eval_r,
    cont_set_var,
    cont_resume,
    cont_closure_application_args,
    cont_exit_atomic,
    cont_read_next_token,
    cont_read_append_continue,
    cont_read_eval_continue,
    cont_read_expect_closepar,
    cont_read_dot_terminate,
    cont_read_done,
    cont_read_quote_result,
    cont_read_commaat_result,
    cont_read_comma_result,
    cont_read_start_array,
    cont_read_append_array,
    cont_map,
    cont_match_guard,
    cont_terminate,
```

```
cont_close_list_in_flash,

cont_qq_expand_start,
    cont_qq_expand,
    cont_qq_append,

cont_qq_expand_list,
```

```
while (true) {
  if (App_K) {
     apply_cont();
  } else {
     /* pattern match on Exp
*/
  }
}
```

Values

- 4 value types:
  - 28Bit Integers, unsigned and signed, characters and symbols.

    $B_{31}..B_4T_1T_0G0$ - B is the value.
- Lots of pointer types (Boxed values)

  $T_5T_4T_3T_2T_1T_0B_{25}..B_2G1$ - B is an index into the heap.
  - 32Bit values.
  - 64 Bit values.
  - Float.
  - Double.

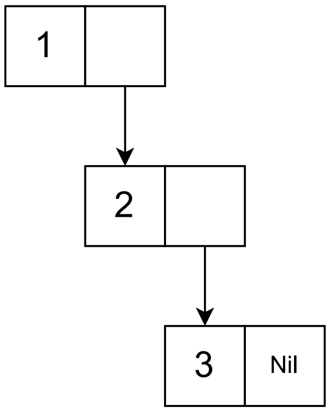
Memory

- Heap
- Buffer memory - “LBM_Memory”
- Flash Storage

Heap

- An array of cells with two fields
  - The car and the cdr. fst/snd. Each 32bit.

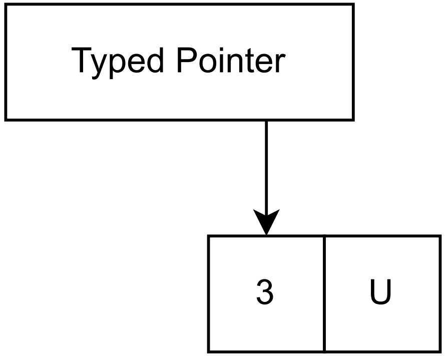
```
(list 1 2 3)
```



Heap

- A 32bit unsigned

3u32



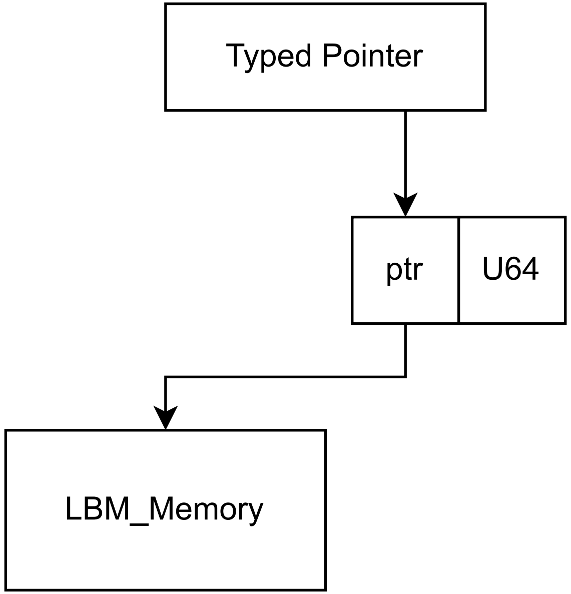
Typed Pointer

3	U

Heap

- A 64bit unsigned

3u64



LBM_Memory

- A memory where N 32 bit words can be allocated and freed. Malloc/free style.
- Lisp values that are larger than a heap cell:

  (pointer_into_lbm_mem . special_id_symbol)

  - GC calls free on these when not needed.
  - GC does not recurse into values stored in lbm memory.

Flash Storage

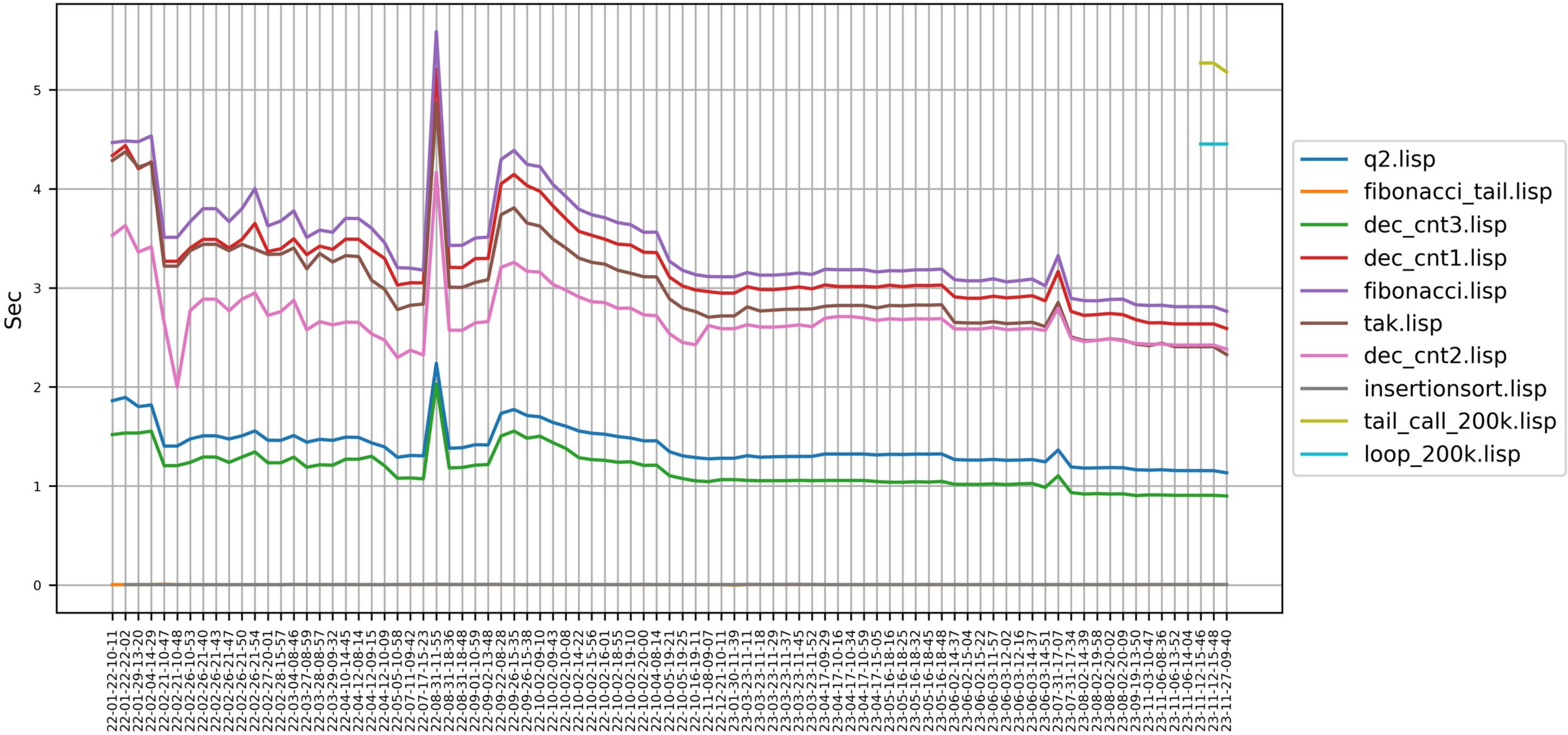
- Cleared in blocks
- Typically value 0xFF in a cleared byte
- Bits can flipped to 0 but not back to 1 individually.

Flash Storage

```
lbm_flash_status lbm_allocate_const_cell(lbm_value *res)
lbm_flash_status lbm_write_const_raw(lbm_uint *data, lbm_uint n, lbm_uint
*res)
lbm_flash_status write_const_cdr(lbm_value cell, lbm_value val)
lbm_flash_status write_const_car(lbm_value cell, lbm_value val)
```

Performance over time

STM32F4 160MHz



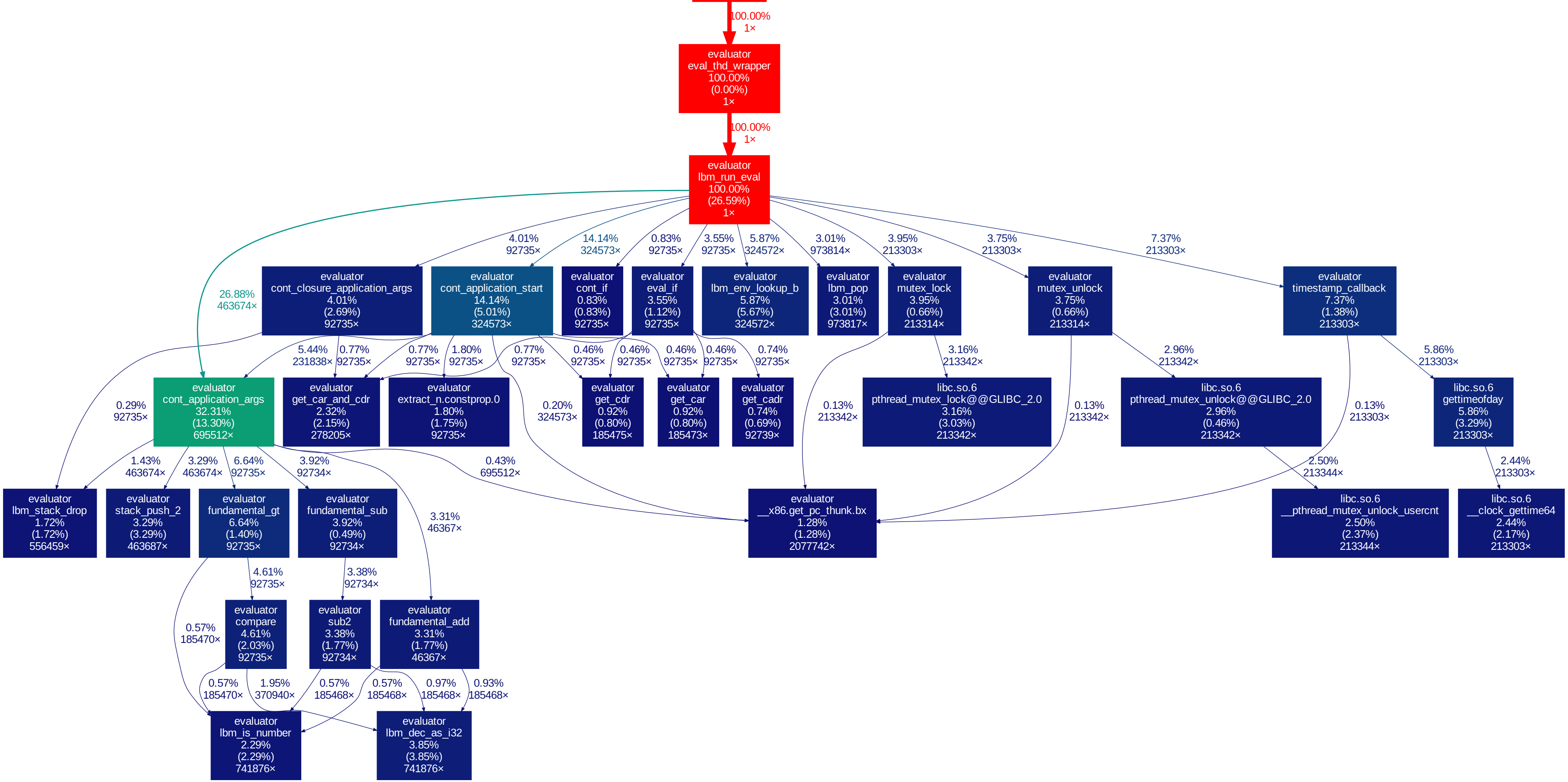
Nfib

- 2.3Mnfib/s (32bit binary on I7-10700)
- 3.1Mnfib/s (64bit binary on I7-10700)

Nfib

- 2.3Mnfib/s (32bit binary on I7-10700)
- 3.1Mnfib/s (64bit binary on I7-10700)

- ~8Mnfib/s (Lennart’s combinators on M1)
- ~10Mnfib/s (Lennart’s combinators on M1 when we talked to him again moments later)


100.00%
1×
evaluator
eval_thd_wrapper
100.00%
(0.00%)
1×
100.00%
1×
evaluator
lbm_run_eval
100.00%
(26.59%)
1×
26.88%
463674×
4.01%
92735×
14.14%
324573×
0.83%
92735×
3.55%
92735×
5.87%
324572×
3.01%
973814×
3.95%
213303×
3.75%
213303×
7.37%
213303×
evaluator
cont_closure_application_args
4.01%
(2.69%)
92735×
evaluator
cont_application_start
14.14%
(5.01%)
324573×
evaluator
cont_if
0.83%
(0.83%)
92735×
evaluator
eval_if
3.55%
(1.12%)
92735×
evaluator
lbm_env_lookup_b
5.87%
(5.67%)
324572×
evaluator
lbm_pop
3.01%
(3.01%)
973817×
evaluator
mutex_lock
3.95%
(0.66%)
213314×
evaluator
mutex_unlock
3.75%
(0.66%)
213314×
evaluator
timestamp_callback
7.37%
(1.38%)
213303×
5.44%
231838×
0.77%
92735×
0.77%
92735×
1.80%
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213342×
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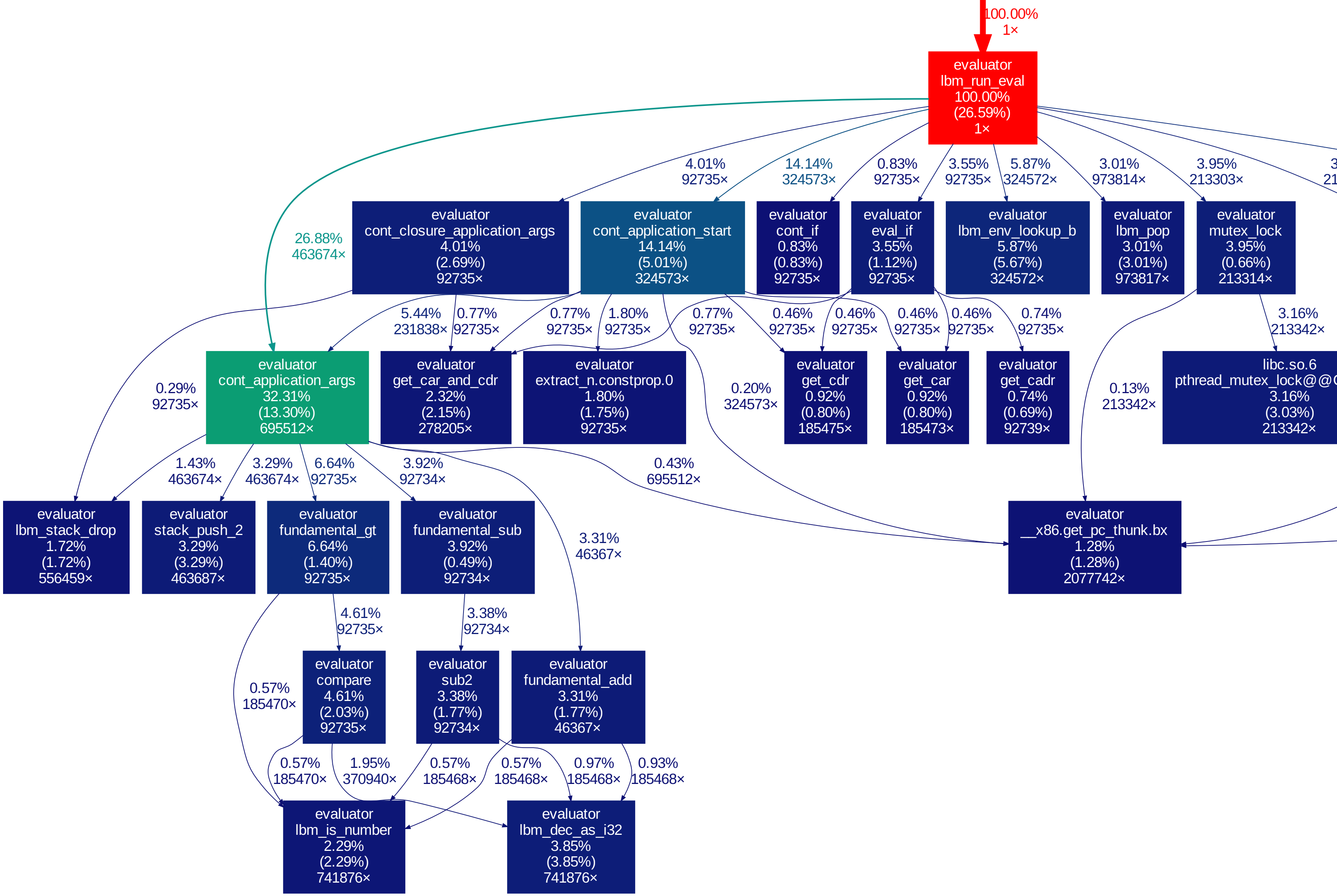
213303×
0.29%
92735×
0.20%
324573×
0.13%
213342×
0.13%
213342×
0.13%
213303×
evaluator
cont_application_args
32.31%
(13.30%)
695512×
evaluator
get_car_and_cdr
2.32%
(2.15%)
278205×
evaluator
extract_n.constprop.0
1.80%
(1.75%)
92735×
evaluator
get_cdr
0.92%
(0.80%)
185475×
evaluator
get_car
0.92%
(0.80%)
185473×
evaluator
get_cadr
0.74%
(0.69%)
92739×
libc.so.6
pthread_mutex_lock@@GLIBC_2.0
3.16%
(3.03%)
213342×
libc.so.6
pthread_mutex_unlock@@GLIBC_2.0
2.96%
(0.46%)
213342×
libc.so.6
gettimeofday
5.86%
(3.29%)
213303×
1.43%
463674×
3.29%
463674×
6.64%
92735×
3.92%
92734×
0.43%
695512×
2.50%
213344×
2.44%
213303×
3.31%
46367×
evaluator
lbm_stack_drop
1.72%
(1.72%)
556459×
evaluator
stack_push_2
3.29%
(3.29%)
463687×
evaluator
fundamental_gt
6.64%
(1.40%)
92735×
evaluator
fundamental_sub
3.92%
(0.49%)
92734×
evaluator
__x86.get_pc_thunk.bx
1.28%
(1.28%)
2077742×
libc.so.6
__pthread_mutex_unlock_usercnt
2.50%
(2.37%)
213344×
libc.so.6
__clock_gettime64
2.44%
(2.17%)
213303×
4.61%
92735×
3.38%
92734×
0.57%
185470×
evaluator
compare
4.61%
(2.03%)
92735×
evaluator
sub2
3.38%
(1.77%)
92734×
evaluator
fundamental_add
3.31%
(1.77%)
46367×
0.57%
185470×
1.95%
370940×
0.57%
185468×
0.57%
185468×
0.97%
185468×
0.93%
185468×
evaluator
lbm_is_number
2.29%
(2.29%)
741876×
evaluator
lbm_dec_as_i32
3.85%
(3.85%)
741876×


100.00%
1×
evaluator
lbm_run_eval
100.00%
(26.59%)
1×
26.88%
463674×
4.01%
92735×
14.14%
324573×
0.83%
92735×
3.55%
92735×
5.87%
324572×
3.01%
973814×
3.95%
213303×
evaluator
cont_closure_application_args
4.01%
(2.69%)
92735×
evaluator
cont_application_start
14.14%
(5.01%)
324573×
evaluator
cont_if
0.83%
(0.83%)
92735×
evaluator
eval_if
3.55%
(1.12%)
92735×
evaluator
lbm_env_lookup_b
5.87%
(5.67%)
324572×
evaluator
lbm_pop
3.01%
(3.01%)
973817×
evaluator
mutex_lock
3.95%
(0.66%)
213314×
5.44%
231838×
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evaluator
cont_application_args
32.31%
(13.30%)
695512×
evaluator
get_car_and_cdr
2.32%
(2.15%)
278205×
evaluator
extract_n.constprop.0
1.80%
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92735×
0.29%
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324573×
evaluator
get_cdr
0.92%
(0.80%)
185475×
evaluator
get_car
0.92%
(0.80%)
185473×
evaluator
get_cadr
0.74%
(0.69%)
92739×
0.13%
213342×
libc.so.6
pthread_mutex_lock@@G
3.16%
(3.03%)
213342×
1.43%
463674×
3.29%
463674×
6.64%
92735×
3.92%
92734×
0.43%
695512×
evaluator
lbm_stack_drop
1.72%
(1.72%)
556459×
evaluator
stack_push_2
3.29%
(3.29%)
463687×
evaluator
fundamental_gt
6.64%
(1.40%)
92735×
evaluator
fundamental_sub
3.92%
(0.49%)
92734×
3.31%
46367×
evaluator
__x86.get_pc_thunk.bx
1.28%
(1.28%)
2077742×
4.61%
92735×
3.38%
92734×
0.57%
185470×
evaluator
compare
4.61%
(2.03%)
92735×
evaluator
sub2
3.38%
(1.77%)
92734×
evaluator
fundamental_add
3.31%
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46367×
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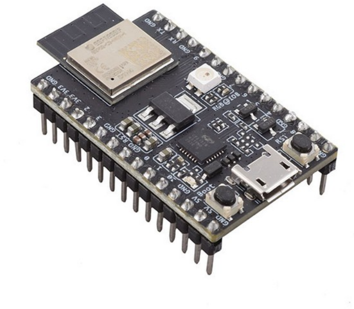
evaluator
lbm_is_number
2.29%
(2.29%)
741876×
evaluator
lbm_dec_as_i32
3.85%
(3.85%)
741876×

TODO

- Look over application and all those special cases.
- Compilation of some kind?
- Maybe some MicroHS inspiration for the GC?
  - The bitmap, the lazy sweep…

To try it out



Buy: esp32c3-devkitm-mini-1 (< 10$£€)

Download: https://vesc-project.com/vesc_tool