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while E do
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Memory is allocated for record expressions.

What if the memory is exhausted?

- let the pgm'er manage the memory?

  easy to implement, but [memory leak (메모리 누수)
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메모리 관리 Memory Management

Choice I. 프로그래머가 책임지게 하자.

$E \rightarrow \vdots$

$\mid$ free x

$$\frac{M(\sigma(x)) = r}{\sigma, M \vdash \text{free } x \Downarrow \cdot, M \setminus \text{range}(r)}$$

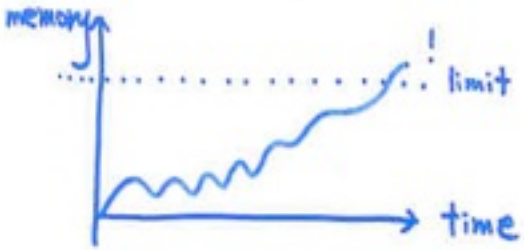
e.g.)

```
type 리스트 = {int x, 리스트 next}
let
    리스트 x := {x:=0, next:={}}
in
    ⋮
    free x;
    ⋮
    {x:=1, next:=...}
    ⋮
end
```

메모리 관리를 프로그래머가 책임지도록하자의 문제점

1. 메모리 출혈 memory leak

- 사용이 끝난 메모리를 너무 오래 잡고있다.
- 재활용이 너무 늦으면



2. 매아가 된 메모리 dangling pointer

- 사용이 끝나기 전에 너무 일찍 재활용시키면


```
free y ;
⋮
x.next    /* was gone! */
```

```
list := {};
for i:=1 to 2**30 do
  list := {node := 0, next := list}
```

```
list := {};
for i:=1 to 2**30 do
  list := {node := 0, next := list}

list := {};
for i:=1 to 1000 do
  list := {node := 0, next := list};
(* use the list *)
free_all(list);
list := {};
for i:= 1 to 1000 do
  list := {node := 0, next := list}
```

```
list := {};
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what if
memory
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Memory leak!

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what if memory is exhausted here? Memory leak!

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x := list.next.next;
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free_all(list);
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```

what if memory is exhausted here? Memory leak!

```
x := list.next.next;

write x.node+1
```

x is a dangling pointer!

프로그래머에게 맡기지 말고
자동으로 메모리를 재활용해 주자.

Modern programming languages supports automatic garbage collection;
ML, Java, C#, Haskell, (Scheme,Prolog)

Face the history, dude: GC becomes the main stream!

Garbage Collection 메모리 재활용

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Once in a while, memory is automatically recycled.

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```
fun eval(E,M,expr) =
  if |M|=too big
  then eval'(E,gc(M),expr)
  else eval'(E,M,expr)

and eval'(E,M,ADD(e1,e2)) = … eval … eval …
  | eval'(E,M,CALL(f,e)) = … eval … eval …
   …
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But we can program an approximate time-machine that is safe.

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every memory access is done through names:
M(E(x)) M(E(x)(age))

the contents of names are determined by the current environment.

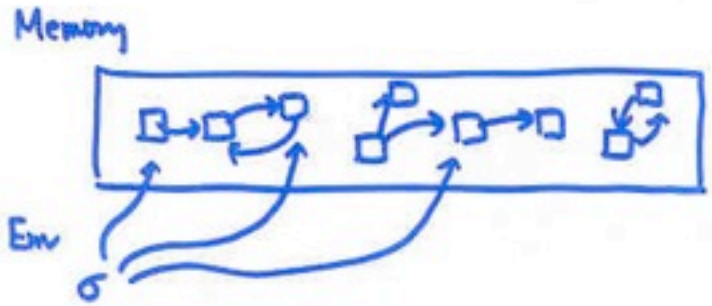
memory cells that can be accessed are those that are reachable from the current environments.

fun gc(E,M) = recycle M, except for those that are reachable from E.

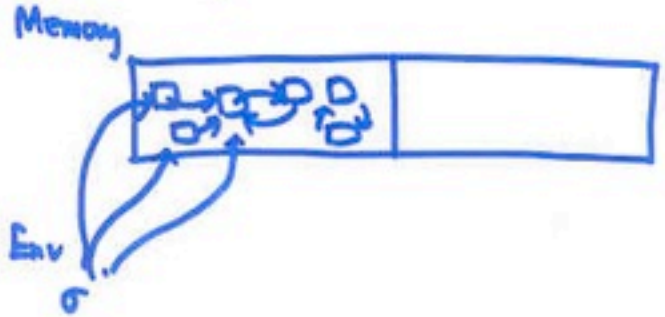
메모리 관리 Memory Management

Choice II. 자동으로 해 주자.
프로그래머는 신경쓰지 않게.

1. Mark & Sweep



2. Stop & Copy



Goal:
GC in 10ms.

메모리 관리 Memory Management

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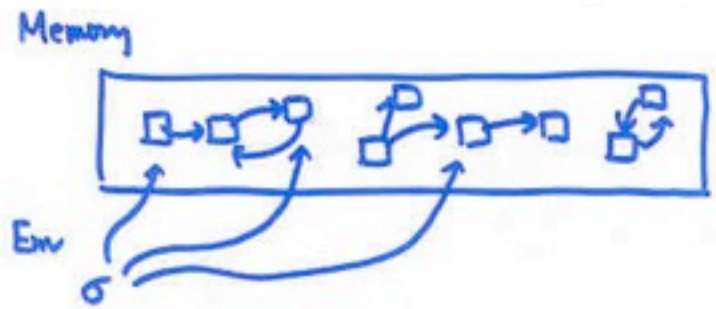

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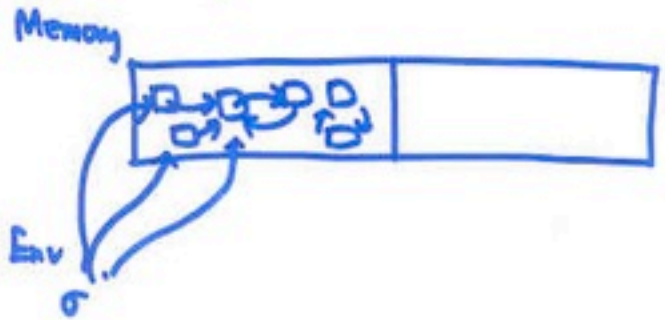

What we have learned

* inductive thinking/programming
  : the powerful method

* inductive language definition
  - syntax
  - evaluation semantics (dynamic semantics)
    ≈ interpreter
  - type system (static semantics)
    ≈ type checker

* imperative language designs
  K−, K
  - what's in the variables (names)
    : location, location block, procedure, type
  - scope, recursion, parameter passing
    type checking/safety, type equivalence, overloading,
    name spaces, and memory management

More to come before Part 2:

-translation/virtual machine

-foreign-language interoperability

Translation/Virtual Machine

compilation/compiler

Translation/Virtual Machine

programs in L1 → programs in L2

compilation/compiler

Translation/Virtual Machine

programs in L1 → programs in L2

semantics semantics

compilation/compiler

Translation/Virtual Machine

programs in L1	→	programs in L2
semantics		semantics
interpreter		interpreter
		circuits

compilation/compiler

Translation/Virtual Machine

programs in L1 → programs in L2

semantics

interpreter

semantics

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circuits

C
nML
Java

x86
JVM
SECD
Krivine

compilation/compiler

integer expression

E -> n | E+E | E-E

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stack machine

(S,C)
stack S
command C

integer expression

E -> n | E+E | E-E

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(S, push n::C) -> (n::S, C)

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stack machine

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cmd = {push n, pop,
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(S, push n::C) -> (n::S, C)
(n::S, pop::C) -> (S, C)
(n2::n1::S, add::C) -> (n1+n2::S, C)
(n2::n1::S, sub::C) -> (n1-n2::S, C)

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Expression E's value appears on top of the stack

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```

Foreign-language Inter-operability

inter-operability between C- and nML
inter-operability between C- and Java
inter-operability between C- and C#

e.g. C- sorts a int list, nML checks and prints the result

e.g. C- computes a sum, Java generates a list of that length

```
fun callx(f,x) =
  x into string s; (* inside C- *)
  read s into y; (* inside nML *)
  call f with y (* inside nML *)
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```
x2s(n) = print_int n
x2s(true) = print "TT"
x2s(false) = print "FF"
x2s() = print "UNIT"
x2s(r) = print "{... }"
```

C- value into string

```
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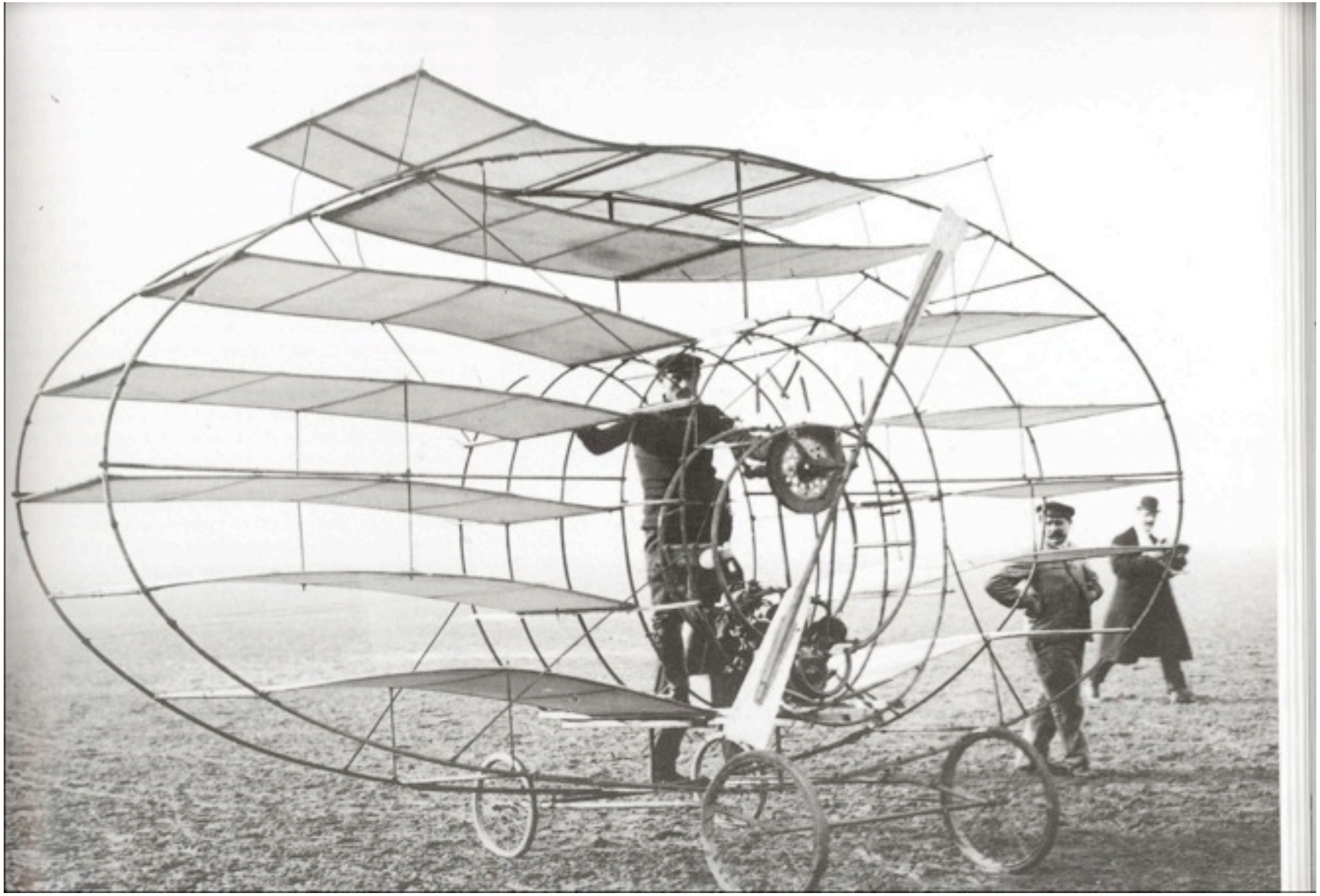
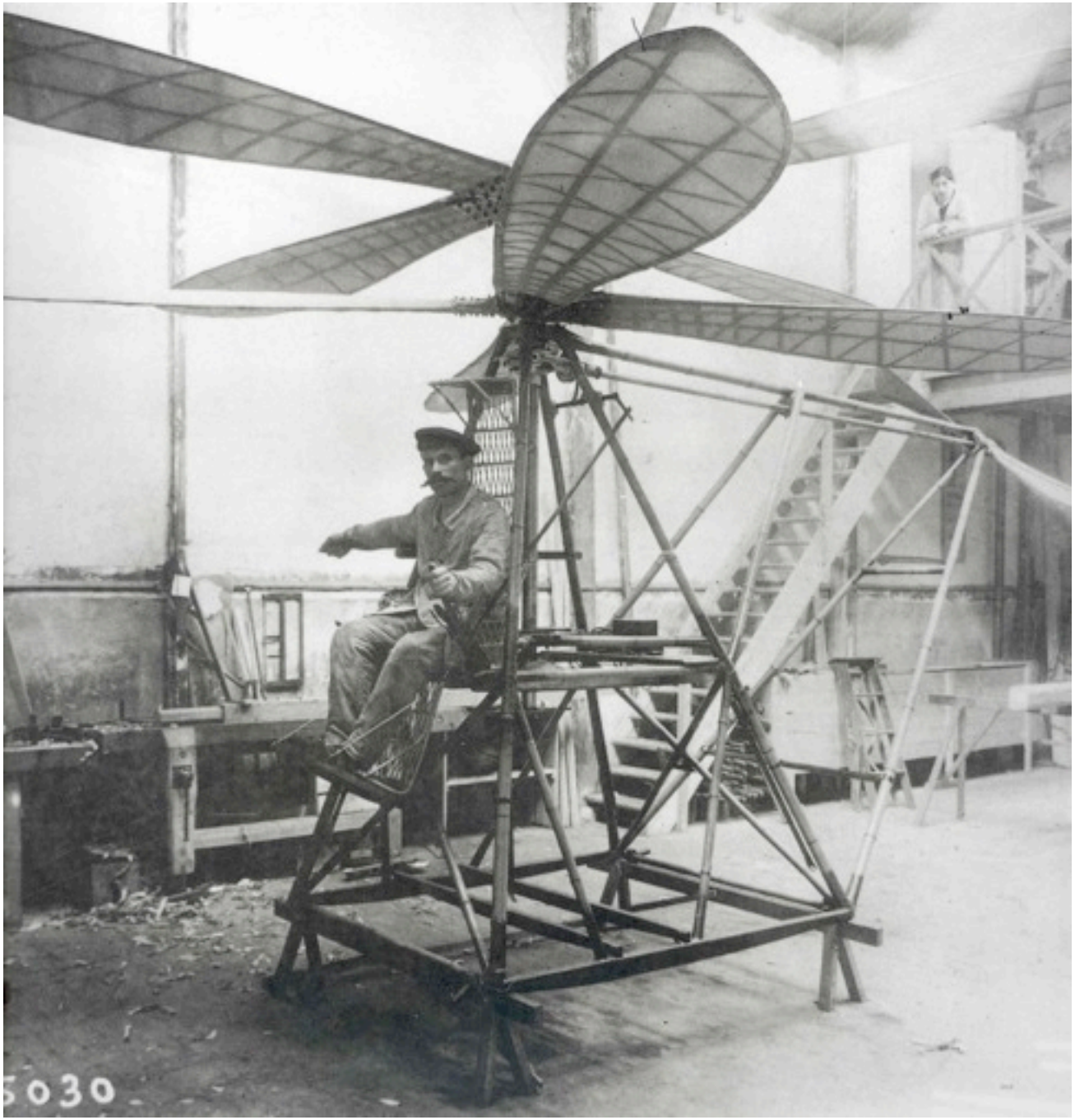
C- value into string

string to nML value




5030