Jam2000 Assembly

```
(ldi R0 0)
(ldi R1 1)


(ldi R2 10)
(sub R2 R0 R2)
(bez R0 6)
(add R0 R0 R1)
(jmpi 2)


(halt)
```

Jam2000 Assembly

```
(ldi R0 0)
(ldi R1 1)


(ldi R2 10)
(sub R2 R0 R2)
(bez R0 6)
(add R0 R0 R1)
(jmpi 2)


(halt)
```

Number addresses like 6 and 2 are a pain...

Jam2000 Assembly and Labels

```
(ldi R0 0)
(ldi R1 1)

(ldi R2 10)
(sub R2 R0 R2)
(bez R0 6)
(add R0 R0 R1)
(jmpi 2)

(halt)
```

=

```
(ldi R0 0)
(ldi R1 1)

(label LOOP)
(ldi R2 10)
(sub R2 R0 R2)
(bez R0 DONE)
(add R0 R0 R1)
(jmpi LOOP)

(label DONE)
(halt)
```

Jam2000 Assembly and Constants

```
(ldi R0 0)
(ldi R1 1)

(label LOOP)
(ldi R2 10)
(sub R2 R0 R2)
(bez R0 DONE)
(add R0 R0 R1)
(jmpi LOOP)

(label DONE)
(halt)
```

=

```
(const COUNT 10)
(ldi R0 0)
(ldi R1 1)

(label LOOP)
(ldi R2 COUNT)
(sub R2 R0 R2)
(bez R0 DONE)
(add R0 R0 R1)
(jmpi LOOP)

(label DONE)
(halt)
```

Jam2000 Aseembly and Data

```
(jmpi PROG)

(label DRAW-CHAR)
(ldi R7 1)
....
(label DONE)
(jmpx R2)

(data FONT-TABLE
      0 0 0 ....)

(label PROG)
....
```

Jam2000 Assembly

A Jam2000 instruction in S-expression form is an ***instruction***, possibly using a ***`name`*** in place of a number

A Jam2000 assembly program is a sequence of ***declarations***

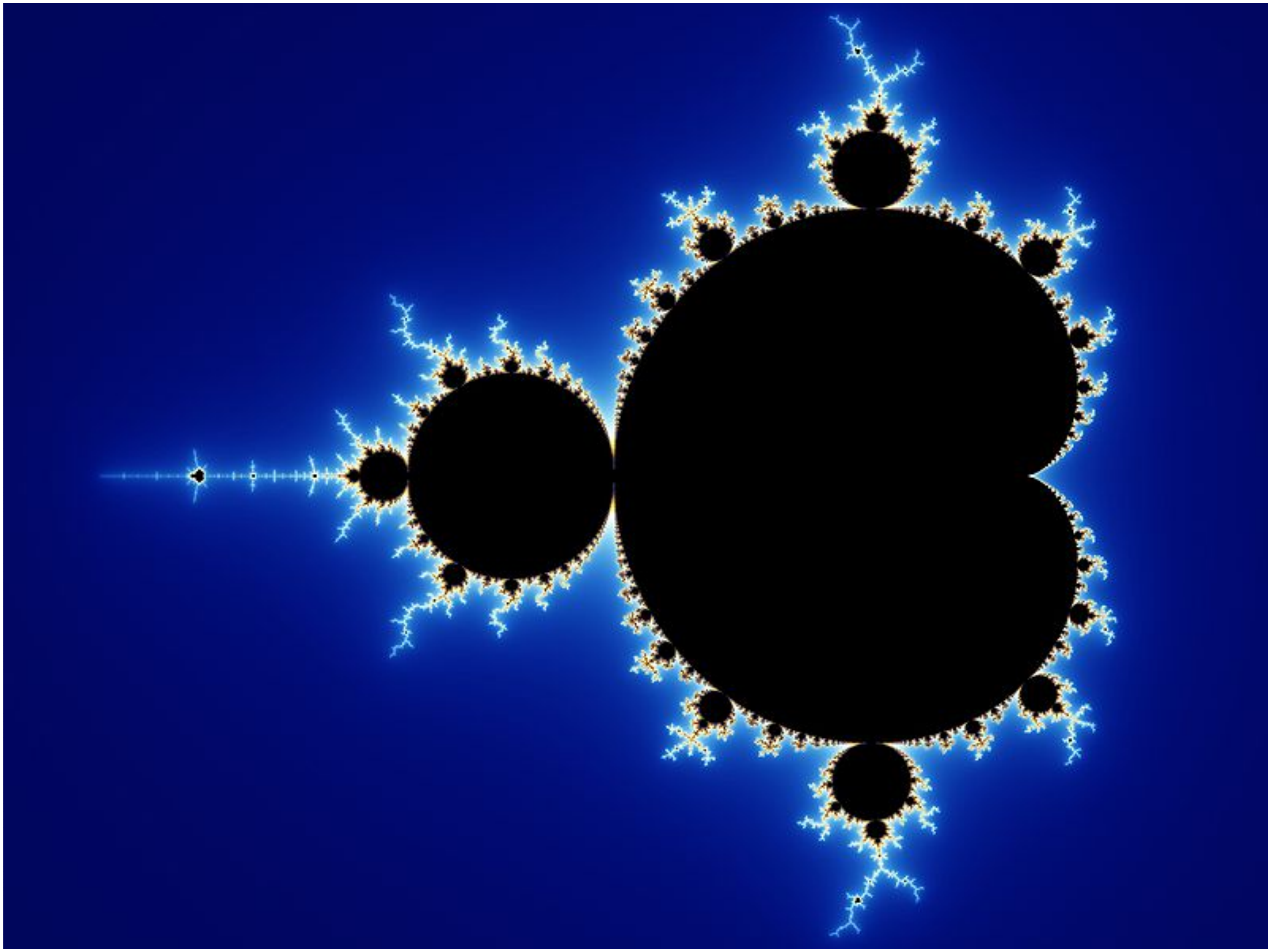
A ***declaration*** is either

- An ***instruction***
- `(label` ***`name`***`)`
- `(const` ***`name`*** ***`num`***`)`
- `(data` ***`name`*** ***`num`*** `...)` where a ***`name`*** can be used in place of a ***`num`***

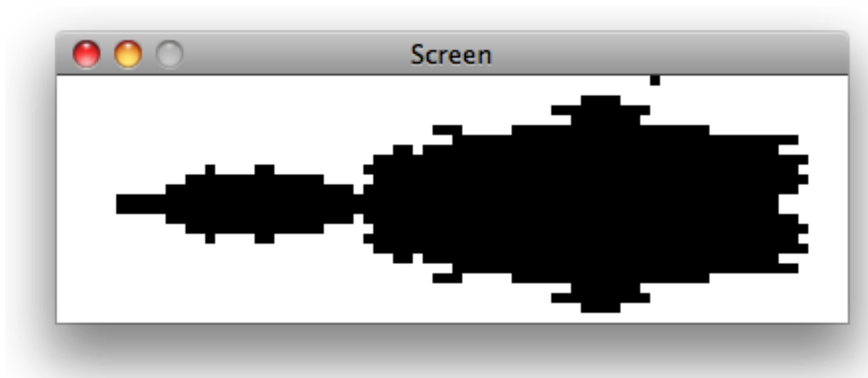
Jam2000 Assembly

- An **instruction** corresponds to a machine code
- `(label` ***`name`***`)` has no machine code, but declares ***`name`*** to be replaced with the count of machine codes that precede the **`label`** declaration
- `(const` ***`name`*** ***`num`***`)` has no machine code, but declares ***`name`*** to be replaced with ***`num`***
- `(data` ***`name`*** ***`num`*** `...)` generates the machine-code sequence ***`num`*** `...` and declares ***`name`*** to be replaced with the number machine codes that precede the **`data`** declaration

Extended Jam2000 Assembly Example: Mandelbrot



Extended Jam2000 Assembly Example: Mandelbrot



Linkers and Loaders

Pieces of a program can be individually assembled, but with some addresses not yet picked

A **linker** puts pieces together, possibly picking some addresses

A **loader** picks remaining addresses at the last minute so that a program can run

(we won't bother with them for Jam2000)

More Data

- Small numbers: obvious
- Booleans: `1` and `0`
- Colors: `0` = black, `9999999` = white, etc.
- Characters: `17` = A, etc.

More Data

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- Booleans: `1` and `0`
- Colors: `0` = black, `9999999` = white, etc.
- Characters: `17` = A, etc.
- Empty: `0`

More Data

- Small numbers: obvious
- Booleans: `1` and `0`
- Colors: `0` = black, `9999999` = white, etc.
- Characters: `17` = A, etc.
- Empty: `0`
- Structure or cons: ???

Compound Data

To represent compound data, use a number that is an address, and store pieces starting at the address:

```
(make-posn 7 99)  ⇒  10
```

0	0	0	0	0	0	0	0
0	0	7	99	0	0	0	0
0	0	0	0	0	0	0	0

Compound Data

To represent compound data, use a number that is an address, and store pieces starting at the address:

```
(cons 8 empty)  ⇒  12
```

0	0	0	0	0	0	0	0
0	0	7	99	8	0	0	0
0	0	0	0	0	0	0	0

Compound Data

To represent compound data, use a number that is an address, and store pieces starting at the address:

```
(cons
 9
 (cons 8 empty))
```

⇒ **14**

0	0	0	0	0	0	0	0
0	0	7	99	8	0	9	12
0	0	0	0	0	0	0	0

Compound Data

To represent compound data, use a number that is an address, and store pieces starting at the address:

```
(cons
 9
 (cons 8 empty))
```

⇒ 14

0	0	0	0	0	0	0	0
0	0	7	99	8	0	9	12
0	0	0	0	0	0	0	0

This works if we never store a cons at address 0

Lists

As data in Jam2000 assembly:

```
(const EMPTY 0)
(data CONS2 3 EMPTY)
(data CONS1 2 CONS2)
```

Sum

```
(label SUM)
; list in R0
; accum in R1
; return address in R2
(bez R0 SUM-DONE)
(ld R9 R0)
(ldi R7 1)
(ldx R0 R0 R7)
(add R1 R1 R9)
(jmpi SUM)
(label SUM-DONE)
(jmpx R2)
```

```
(label MAIN-SUM)

(ldi R0 CONS1)
(ldi R1 0)
(ldi R2 MAIN-SUM-RETURN)

(jmpi SUM)

(label MAIN-SUM-RETURN)
(print R1)
(newline)
(halt)
```

Sum

```
(label SUM)
; list in
; accum in
; return address in R2
(bez R0 SUM-DONE)
(ld R9 R0)
(ldi R7 1)
(ldx R0 R0 R7)
(add R1 R1 R9)
(jmpi SUM)
(label SUM-DONE)
(jmpx R2)
```

empty? test on argument

```
(label MAIN-SUM)

(ldi R0 CONS1)
(ldi R1 0)
(ldi R2 MAIN-SUM-RETURN)

(jmpi SUM)

(label MAIN-SUM-RETURN)
(print R1)
(newline)
(halt)
```

Sum

```
(label SUM)
; list in R0
; accum in
; return ad
(bez R0 SUM-DONE)
(ld R9 R0)
(ldi R7 1)
(ldx R0 R0 R7)
(add R1 R1 R9)
(jmpi SUM)
(label SUM-DONE)
(jmpx R2)
```

```
(label MAIN-SUM)

(ldi R0 CONS1)
(ldi R1 0)
(ldi R2 MAIN-SUM-RETURN)

(jmpi SUM)

(label MAIN-SUM-RETURN)
(print R1)
(newline)
(halt)
```

`first` of argument

Sum

```
(label SUM)
; list in R0
; accum in R1
; return address in R2
(bez R0 SUM-DONE)
(ld R9 R0)
(ldi R7 1)
(ldx R0 R0 R7)
(add R1 R1 R9)
(jmpi SUM)
(label SUM-DONE)
(jmpx R2)
```

rest of argument

```
(label MAIN-SUM)

(ldi R0 CONS1)
(ldi R1 0)
(ldi R2 MAIN-SUM-RETURN)

(jmpi SUM)

(label MAIN-SUM-RETURN)
(print R1)
(newline)
(halt)
```

Sum

```
(label SUM)
; list in R0
; accum in R1
; return address in R2
(bez R0 SUM-DONE)
(ld R9 R0)
(ldi R7 1)
(ldx R0 R0 R7
(add R1 R1 R9)
(jmpi SUM)
(label SUM-DONE)
(jmpx R2)
```

accumulate result

```
(label MAIN-SUM)

(ldi R0 CONS1)
(ldi R1 0)
(ldi R2 MAIN-SUM-RETURN)

i SUM)

(label MAIN-SUM-RETURN)
(print R1)
(newline)
(halt)
```

Sum

```
(label SUM)
; list in R0
; accum in R1
; return address in R2
(bez R0 SUM-DONE)
(ld R9 R0)
(ldi R7 1)
(ldx R0 R0 R7)
(add R1 R1 R9)
(jmpi SUM)
(label SUM-
(jmpx R2)
```

recur on `rest`

```
(label MAIN-SUM)

(ldi R0 CONS1)
(ldi R1 0)
(ldi R2 MAIN-SUM-RETURN)

(jmpi SUM)

(label MAIN-SUM-RETURN)
(print R1)
ewline)
alt)
```

Sum

```
(label SUM)
; list in R0
; accum in R1
; return address in R2
(bez R0 SUM-DONE)
(ld R9 R0)
(ldi R7 1)
(ldx R0 R0 R7)
(add R1 R1 R9)
(jmpi SUM)
(label SUM-DONE)
(jmpx R2)
```

```
(label MAIN-SUM)

(ldi R0 CONS1)
(ldi R1 0)
(ldi R2 MAIN-SUM-RETURN)

(jmpi SUM)

(label MAIN-SUM-RETURN)
(print R1)
(newline)
(halt)
```

Allocation

How about `reverse`?

Allocation

How about `reverse`?

A `cons` needs to ***allocate***:

- Designate some address `ALLOC-PTR` to point to free space
- Initialize `ALLOC-PTR` to the area past all the code
- Increment `ALLOC-PTR` for each `cons`

Allocation

```
(const ALLOC-PTR 7)
```

1	33	9	80	6	77	2	8
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Allocation

```
(const ALLOC-PTR 7)
(cons 91 empty) ; = 8
```

1	33	9	80	6	77	2	10
91	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Allocation

```
(const ALLOC-PTR 7)
(cons 5 (cons 91 empty)) ; = 10
```

1	33	9	80	6	77	2	12
91	0	5	8	0	0	0	0
0	0	0	0	0	0	0	0

Allocation

see **`REVERSE`** in **`list.jam`**

Non-Loop Recursion

What about **`feed-fish`**?

Non-Loop Recursion

What about **`feed-fish`**?

```
(label MAIN-FEED)
....
(ldi R2 MAIN-FEED-RETURN1)
(jmpi FEED) ....
(label MAIN-FEED-RETURN1) ....


(label FEED)
....
(ldi R2 FEED-BACK)
(jmpi FEED) ....
(label FEED-BACK) ....
```

Non-Loop Recursion

What about **`feed-fish`**?

```
(label MAIN-FEED)
....
(ldi R2 MAIN-FEED-RETURN1)
(jmpi FEED) ....
(label MAIN-FEED-RETURN1) ....


(label FEED)
....
(ldi R2 FEED-BACK)
(jmpi FEED) ....
(label FEED-BACK) ....
```

A single return register isn't enough

Continuation

Instead of a single return address, keep a list of return addresses

For **`FEED`**, this list also needs to remember the number to add after returning

Continuation

Instead of a single return address, keep a list of return addresses

For **`FEED`**, this list also needs to remember the number to add after returning

Danger: if we don't get rid of the continuation conses, then we might run out of memory

- Discard each cons just before returning

Stack

A ***stack*** is an alternative to a list, especially for continuations

Typically, a register like **`R6`** holds the stack pointer instead of a memory address like **`ALLOC-PTR`**

\+ Simpler allocation

\+ Simpler discard

− Splits memory between stack and allocation

```
(data STACK
      0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0)
```

Stack

see **`FEED`** in **`list.jam`**