```
#|

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|#
```

EVENT: Start with the library "mc20-2" using the compiled version.

```
;            Proof of the Correctness of a ZERO Program
#|
```

This program zeros an integer array.

```
/* zeros an array */
zero(a, n)
int a[], n;
{
  int i;
  for (i = 0; i < n; ++i)
    a[i] = 0;
}
```

Here, in symbolic form, is the above program in MC68k instructions. The machine code is produced by "gcc -O".

```
a6@8,  the first argument which is the starting address of the array A.
a6@12, the second argument which is the number of the elements we are zeroing.
a6@-4, the local variable i which serves as a counter.

0x2328 <zero>:         linkw a6,#0
0x232c <zero+4>: moveal a6@(8),a0
0x2330 <zero+8>: movel a6@(12),d1
0x2334 <zero+12>: clrl d0
0x2336 <zero+14>: cmpl d0,d1
0x2338 <zero+16>: ble 0x2344 <zero+28>
0x233a <zero+18>: clrl 0(a0)[d0.l*4]
0x233e <zero+22>: addql #1,d0
0x2340 <zero+24>: cmpl d0,d1
0x2342 <zero+26>: bgt 0x233a <zero+18>
0x2344 <zero+28>: unlk a6
0x2346 <zero+30>: rts

The machine code of the above program is:

<zero>:      0x4e56  0x0000  0x206e  0x0008  0x222e  0x000c  0x4280  0xb280
<zero+16>:   0x6f0a  0x42b0  0x0c00  0x5280  0xb280  0x6ef6  0x4e5e  0x4e75

'(78      86      0       0       32      110     0       8
  34      46      0       12      66      128     178     128
  111     10      66      176     12      0       82      128
  178     128     110     246     78      94      78      117)
|#

; machine code for ZERO.
```

DEFINITION:
ZERO-CODE
= `'(78 86 0 0 32 110 0 8 34 46 0 12 66 128 178 128 111 10 66 176 12 0 82 128 178 128 110 246 78 94 78 117)`

DEFINITION:
clr-lst $(i,\ n,\ lst)$
= **if** $i < n$ **then** clr-lst $(1 + i,\ n,$ put-nth $(0,\ i,\ lst))$
else lst **endif**

DEFINITION:
zero1-t $(i,\ n)$
= **if** $i < n$ **then** splus $(4,$ zero1-t $(1 + i,\ n))$
else 4 **endif**

DEFINITION:
zero-t (n)
$=$ **if** $n \simeq$ 0 **then** 8
else splus (8, zero1-t (1, n)) **endif**

DEFINITION:
zero-induct (s, i, n, lst)
$=$ **if** $i < n$ **then** zero-induct (stepn (s, 4), $1 + i$, n, put-nth (0, i, lst))
else t endif

DEFINITION:
zero-statep (s, a, n, lst)
$=$ ((mc-status (s) = 'running)
$\wedge$ evenp (mc-pc (s))
$\wedge$ rom-addrp (mc-pc (s), mc-mem (s), 32)
$\wedge$ mcode-addrp (mc-pc (s), mc-mem (s), ZERO-CODE)
$\wedge$ ram-addrp (sub (32, 4, read-sp (s)), mc-mem (s), 16)
$\wedge$ mem-lst (4, a, mc-mem (s), n, lst)
$\wedge$ ram-addrp (a, mc-mem (s), $4 * n$)
$\wedge$ disjoint (a, $4 * n$, sub (32, 4, read-sp (s)), 16)
$\wedge$ (a = read-mem (add (32, read-sp (s), 4), mc-mem (s), 4))
$\wedge$ (n = iread-mem (add (32, read-sp (s), 8), mc-mem (s), 4))
$\wedge$ uint-rangep ($4 * n$, 32)
$\wedge$ ($n \in \mathbf{N}$))

DEFINITION:
zero-s0p (s, a, i, n, lst)
$=$ ((mc-status (s) = 'running)
$\wedge$ evenp (mc-pc (s))
$\wedge$ rom-addrp (sub (32, 24, mc-pc (s)), mc-mem (s), 32)
$\wedge$ mcode-addrp (sub (32, 24, mc-pc (s)), mc-mem (s), ZERO-CODE)
$\wedge$ ram-addrp (read-an (32, 6, s), mc-mem (s), 16)
$\wedge$ mem-lst (4, a, mc-mem (s), n, lst)
$\wedge$ ram-addrp (a, mc-mem (s), $4 * n$)
$\wedge$ disjoint (a, $4 * n$, read-an (32, 6, s), 16)
$\wedge$ (a = read-an (32, 0, s))
$\wedge$ (i = nat-to-int (read-dn (32, 0, s), 32))
$\wedge$ (n = nat-to-int (read-dn (32, 1, s), 32))
$\wedge$ uint-rangep ($4 * n$, 32)
$\wedge$ ($i \in \mathbf{N}$)
$\wedge$ ($n \in \mathbf{N}$)
$\wedge$ ($i \leq n$))

```
; from s to exit: s --> sn.
```

THEOREM: zero-s-sn
(zero-statep (s, a, n, lst) $\wedge$ ($n \simeq$ 0))
$\rightarrow$ ((mc-status (stepn (s, 8)) = 'running)
$\wedge$ (mc-pc (stepn (s, 8)) = rts-addr (s))
$\wedge$ mem-lst (4, a, mc-mem (stepn (s, 8)), n, lst)
$\wedge$ (read-rn (32, 14, mc-rfile (stepn (s, 8)))
= read-rn (32, 14, mc-rfile (s)))
$\wedge$ (read-rn (32, 15, mc-rfile (stepn (s, 8)))
= add (32, read-rn (32, 15, mc-rfile (s)), 4)))

THEOREM: zero-s-sn-rfile
(zero-statep (s, a, n, lst) $\wedge$ d2-7a2-5p (rn) $\wedge$ ($n \simeq$ 0))
$\rightarrow$ (read-rn ($oplen$, rn, mc-rfile (stepn (s, 8)))
= read-rn ($oplen$, rn, mc-rfile (s)))

THEOREM: zero-s-sn-mem
(zero-statep (s, a, n, lst)
$\wedge$ disjoint (sub (32, 4, read-sp (s)), 16, x, k)
$\wedge$ ($n \simeq$ 0))
$\rightarrow$ (read-mem (x, mc-mem (stepn (s, 8)), k) = read-mem (x, mc-mem (s), k))

```
; from s to s0: s --> s0.
```

THEOREM: zero-s-s0
(zero-statep (s, a, n, lst) $\wedge$ ($n \not\simeq$ 0))
$\rightarrow$ zero-s0p (stepn (s, 8), a, 1, n, put-nth (0, 0, lst))

THEOREM: zero-s-s0-other
(zero-statep (s, a, n, lst) $\wedge$ ($n \not\simeq$ 0))
$\rightarrow$ ((linked-rts-addr (stepn (s, 8)) = rts-addr (s))
$\wedge$ (linked-a6 (stepn (s, 8)) = read-an (32, 6, s))
$\wedge$ (read-rn (32, 14, mc-rfile (stepn (s, 8)))
= sub (32, 4, read-sp (s))))

THEOREM: zero-s-s0-rfile
(zero-statep (s, a, n, lst) $\wedge$ d2-7a2-5p (rn) $\wedge$ ($n \not\simeq$ 0))
$\rightarrow$ (read-rn ($oplen$, rn, mc-rfile (stepn (s, 8)))
= read-rn ($oplen$, rn, mc-rfile (s)))

THEOREM: zero-s-s0-mem
(zero-statep (s, a, n, lst)
$\wedge$ disjoint (sub (32, 4, read-sp (s)), 16, x, k)
$\wedge$ disjoint (a, 4 $*$ n, x, k)
$\wedge$ ($n \not\simeq$ 0))
$\rightarrow$ (read-mem (x, mc-mem (stepn (s, 8)), k) = read-mem (x, mc-mem (s), k))

```
; from s0 to exit:  s0 --> sn. By induction.
; base case: s0 --> sn, if i >= n.
```

THEOREM: zero-s0-sn-base
(zero-s0p (s, a, i, n, lst) $\wedge$ ($i \not< n$))
$\rightarrow$ ((mc-status (stepn (s, 4)) = 'running)
$\wedge$ (mc-pc (stepn (s, 4)) = linked-rts-addr (s))
$\wedge$ mem-lst (4, a, mc-mem (stepn (s, 4)), n, lst)
$\wedge$ (read-rn (32, 14, mc-rfile (stepn (s, 4))) = linked-a6 (s))
$\wedge$ (read-rn (32, 15, mc-rfile (stepn (s, 4)))
= add (32, read-an (32, 6, s), 8)))

THEOREM: zero-s0-sn-mem-base
(zero-s0p (s, a, i, n, lst) $\wedge$ ($i \not< n$))
$\rightarrow$ (read-mem (x, mc-mem (stepn (s, 4)), k) = read-mem (x, mc-mem (s), k))

THEOREM: zero-s0-sn-rfile-base
(zero-s0p (s, a, i, n, lst) $\wedge$ d2-7a2-5p (rn) $\wedge$ ($i \not< n$))
$\rightarrow$ (read-rn ($oplen$, rn, mc-rfile (stepn (s, 4)))
= read-rn ($oplen$, rn, mc-rfile (s)))

```
; induction case: s0 --> s0, if i < n.
```

THEOREM: zero-s0-s0
(zero-s0p (s, a, i, n, lst) $\wedge$ ($i < n$))
$\rightarrow$ (zero-s0p (stepn (s, 4), a, $1 + i$, n, put-nth (0, i, lst))
$\wedge$ (read-rn ($oplen$, 14, mc-rfile (stepn (s, 4)))
= read-rn ($oplen$, 14, mc-rfile (s)))
$\wedge$ (linked-a6 (stepn (s, 4)) = linked-a6 (s))
$\wedge$ (linked-rts-addr (stepn (s, 4)) = linked-rts-addr (s)))

THEOREM: zero-s0-s0-mem
(zero-s0p (s, a, i, n, lst) $\wedge$ disjoint (a, $4 * n$, x, k) $\wedge$ ($i < n$))
$\rightarrow$ (read-mem (x, mc-mem (stepn (s, 4)), k) = read-mem (x, mc-mem (s), k))

THEOREM: zero-s0-s0-rfile
(zero-s0p (s, a, i, n, lst) $\wedge$ d2-7a2-5p (rn) $\wedge$ ($i < n$))
$\rightarrow$ (read-rn ($oplen$, rn, mc-rfile (stepn (s, 4)))
= read-rn ($oplen$, rn, mc-rfile (s)))

EVENT: Disable zero-statep.

EVENT: Disable zero-s0p.

```
; put together: s0 --> sn.
```

THEOREM: zero-s0-sn
zero-s0p (s, a, i, n, lst)
$\rightarrow$ ((mc-status (stepn (s, zero1-t (i, n))) = 'running)
$\wedge$ (mc-pc (stepn (s, zero1-t (i, n))) = linked-rts-addr (s))
$\wedge$ mem-lst (4, a, mc-mem (stepn (s, zero1-t (i, n))), n, clr-lst (i, n, lst))
$\wedge$ (read-rn (32, 14, mc-rfile (stepn (s, zero1-t (i, n))))
= linked-a6 (s))
$\wedge$ (read-rn (32, 15, mc-rfile (stepn (s, zero1-t (i, n))))
= add (32, read-an (32, 6, s), 8)))

THEOREM: zero-s0-sn-mem
(zero-s0p (s, a, i, n, lst)
$\wedge$ disjoint (read-an (32, 6, s), 16, x, k)
$\wedge$ disjoint (a, 4 $*$ n, x, k))
$\rightarrow$ (read-mem (x, mc-mem (stepn (s, zero1-t (i, n))), k)
= read-mem (x, mc-mem (s), k))

THEOREM: zero-s0-sn-rfile
(zero-s0p (s, a, i, n, lst) $\wedge$ d2-7a2-5p (rn))
$\rightarrow$ (read-rn ($oplen$, rn, mc-rfile (stepn (s, zero1-t (i, n))))
= read-rn ($oplen$, rn, mc-rfile (s)))

```
; the correctness of the program ZERO.
```

THEOREM: zero-correctness
zero-statep (s, a, n, lst)
$\rightarrow$ ((mc-status (stepn (s, zero-t (n))) = 'running)
$\wedge$ (mc-pc (stepn (s, zero-t (n))) = rts-addr (s))
$\wedge$ mem-lst (4, a, mc-mem (stepn (s, zero-t (n))), n, clr-lst (0, n, lst))
$\wedge$ (read-an (32, 6, stepn (s, zero-t (n))) = read-an (32, 6, s))
$\wedge$ (read-an (32, 7, stepn (s, zero-t (n)))
= add (32, read-an (32, 7, s), 4)))

THEOREM: zero-mem
(zero-statep (s, a, n, lst)
$\wedge$ disjoint (sub (32, 4, read-sp (s)), 16, x, k)
$\wedge$ disjoint (a, 4 $*$ n, x, k))
$\rightarrow$ (read-mem (x, mc-mem (stepn (s, zero-t (n))), k) = read-mem (x, mc-mem (s), k))

THEOREM: zero-rfile
(zero-statep (s, a, n, lst) $\wedge$ d2-7a2-5p (rn))
$\rightarrow$ (read-rn ($oplen$, rn, mc-rfile (stepn (s, zero-t (n))))
= read-rn ($oplen$, rn, mc-rfile (s)))

EVENT: Disable zero-t.

```
; we next need to prove that clr-lst does clear the list.
```

THEOREM: zero-lst-la1
$(j < i) \rightarrow (\text{get-nth}\,(j,\ \text{clr-lst}\,(i,\ n,\ lst)) = \text{get-nth}\,(j,\ lst))$

THEOREM: zero-lst-la2
$\text{get-nth}\,(i,\ \text{clr-lst}\,(i,\ n,\ lst))$
$=$ **if** $i < n$ **then** 0
else $\text{get-nth}\,(i,\ lst)$ **endif**

```
; clr-lst does clear the list.
```

THEOREM: clr-lst-clear
$((i \leq j) \wedge (j < n)) \rightarrow (\text{get-nth}\,(j,\ \text{clr-lst}\,(i,\ n,\ lst)) = 0)$

THEOREM: clr-lst-clear-0
$(j < n) \rightarrow (\text{get-nth}\,(j,\ \text{clr-lst}\,(0,\ n,\ lst)) = 0)$

Index

add, 3–6

clr-lst, 2, 6, 7
clr-lst-clear, 7
clr-lst-clear-0, 7

d2-7a2-5p, 4–6
disjoint, 3–6

evenp, 3

get-nth, 7

iread-mem, 3

linked-a6, 4–6
linked-rts-addr, 4–6

mc-mem, 3–6
mc-pc, 3–6
mc-rfile, 4–6
mc-status, 3–6
mcode-addrp, 3
mem-lst, 3–6

nat-to-int, 3

put-nth, 2–5

ram-addrp, 3
read-an, 3–6
read-dn, 3
read-mem, 3–6
read-rn, 4–6
read-sp, 3, 4, 6
rom-addrp, 3
rts-addr, 4, 6

splus, 2, 3
stepn, 3–6
sub, 3, 4, 6

uint-rangep, 3

zero-code, 2, 3
zero-correctness, 6
zero-induct, 3
zero-lst-la1, 7
zero-lst-la2, 7
zero-mem, 6
zero-rfile, 6
zero-s-s0, 4
zero-s-s0-mem, 4
zero-s-s0-other, 4
zero-s-s0-rfile, 4
zero-s-sn, 4
zero-s-sn-mem, 4
zero-s-sn-rfile, 4
zero-s0-s0, 5
zero-s0-s0-mem, 5
zero-s0-s0-rfile, 5
zero-s0-sn, 6
zero-s0-sn-base, 5
zero-s0-sn-mem, 6
zero-s0-sn-mem-base, 5
zero-s0-sn-rfile, 6
zero-s0-sn-rfile-base, 5
zero-s0p, 3–6
zero-statep, 3, 4, 6
zero-t, 3, 6
zero1-t, 2, 3, 6