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DC-10 Return To Flight

FLG-09 FlightSim LAN Gardermoen
10 oktober 2009

domestic title page

En Simulator i fem hundre Kilobyte! (0,0005 GB)

Alt du alltid ønsket å vite om DC-10 og gamle datamaskiner, men var redd for å spørre

Geert Rolf
Huset for Pensjonerte og Gamle Datamaskiner,
Privat museum,
Winssen, Nederland

DC-10 Return To Flight

FLG-09 FlightSim LAN Gardermoen
October 10, 2009

international title page

A Simulator in five hundred Kilobyte! (0.0005 GB)

Everything you always wanted to know about the DC-10 and its old computers, but were afraid to ask.

Geert Rolf
House for Old and Retired Computers,
Private museum,
Winssen, The Netherlands

This Talk

- Will give you an idea
  - how this Link Miles DC-10 Sim works
  - about |d|i|g|i|t|a|l| PDP-11 minicomputers
  - how our work evolved over the time
  - *of some technical stuff, some human factors too*

Who are we?

- <u>Geert Rolf</u>
  - HTS Software Engineering
  - *First contact* with a |d|i|g|i|t|a|l| PDP-11 in 1977
  - Mainly focussed on Unix, C and IP networks
  - Never did a realtime application

- <u>Warner Krelekamp</u>
  - HTS Mechanical Engineering
  - *Hooked on electronics*
  - Worked 14 years for |d|i|g|i|t|a|l| at European Repair Center in Nijmegen

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How it all started...

- Geert to Jan Fjeld, december 5, 2007:
  A little amazed I was after reading the story of the DC-10 simulator. I'm a flightsimmer, but also a computer collector and known to lot of details (both hardware and software) of various PDP-11 systems.
  Need help, tips, hints or advice?? Be my guest.
- Geert to Warner, december 10, 2007:
  Zin om in Noorwegen PDPs te repareren??

  (fancy repairing PDPs in Norway?)

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What is a PDP-11?

- On the market since April 1970 (– early 90s)
- Air cooled, cheap: affordable for industry.
- Industrial automation: data acquisition and control systems.
- Time sharing (> 30 users) on later, bigger machines.

- 16 bit minicomputer:
  - 64 Kbyte is a hard limit for a single program
  - Users work on ASCII terminals – no graphics!
- PDP-11 most popular computer of the '70s.

Three main architectures

- Small machine: upto 56KB memory
- Medium machine: upto 248 KB memory
  - 18 bit physical addresses.
  - Memory Management Unit (MMU):
    - maps 16 bit logical address to 18 bit physical address.
    - 64 KB program = 8 sections of 8KB each.
    - Provides protection: Kernel, Supervisor and User mode. (O.S. Controls MMU.)
- Large machine: upto 3840 KB memory
    - via dedicated memory bus: 22 bit physical addresses
    - All peripherals via 18 bit Unibus.

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A small-size PDP-11

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A medium-size PDP-11

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A large-size PDP-11

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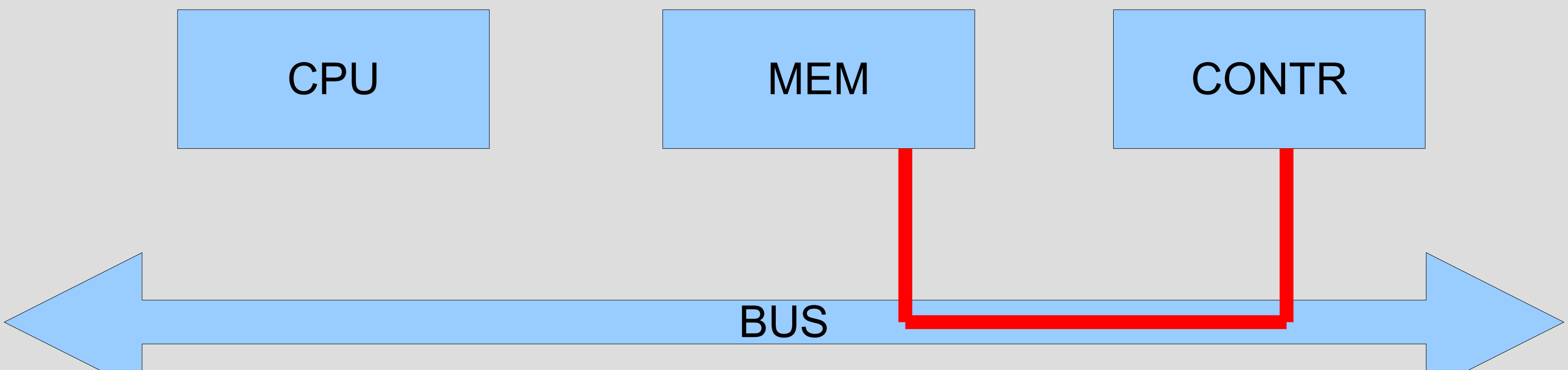
You should know what DMA is!

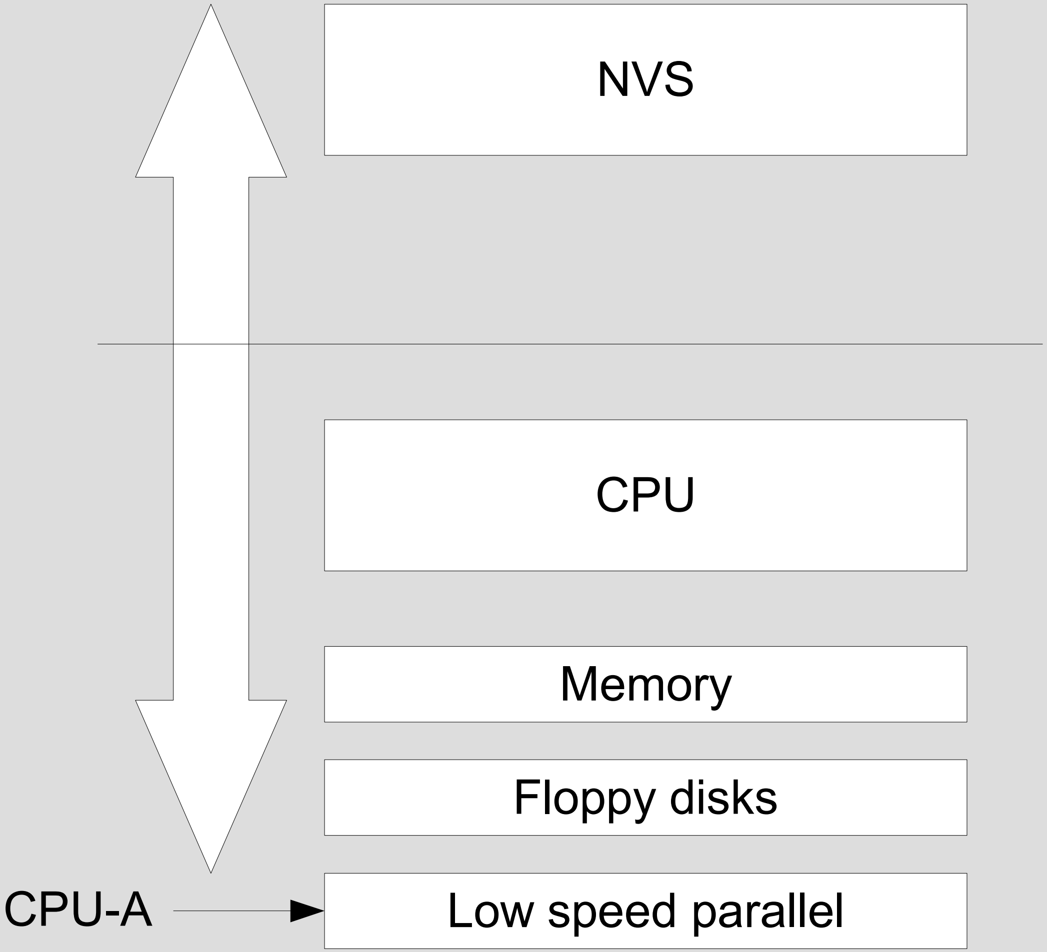


Direct Memory Access: I/O without processor load

- O.S. commands controller
- Controller gets/puts data from/into memory
- Reports ready to O.S. by interrupt

CPU-C

- **CPU-C: PDP 11/45**
  - 56KB
  - dual drive 8” floppy (250KB each)
  - Low speed parallel interface connected with CPU-A
  - bus cable goes into Night Vision System



How does CPU-C look like?

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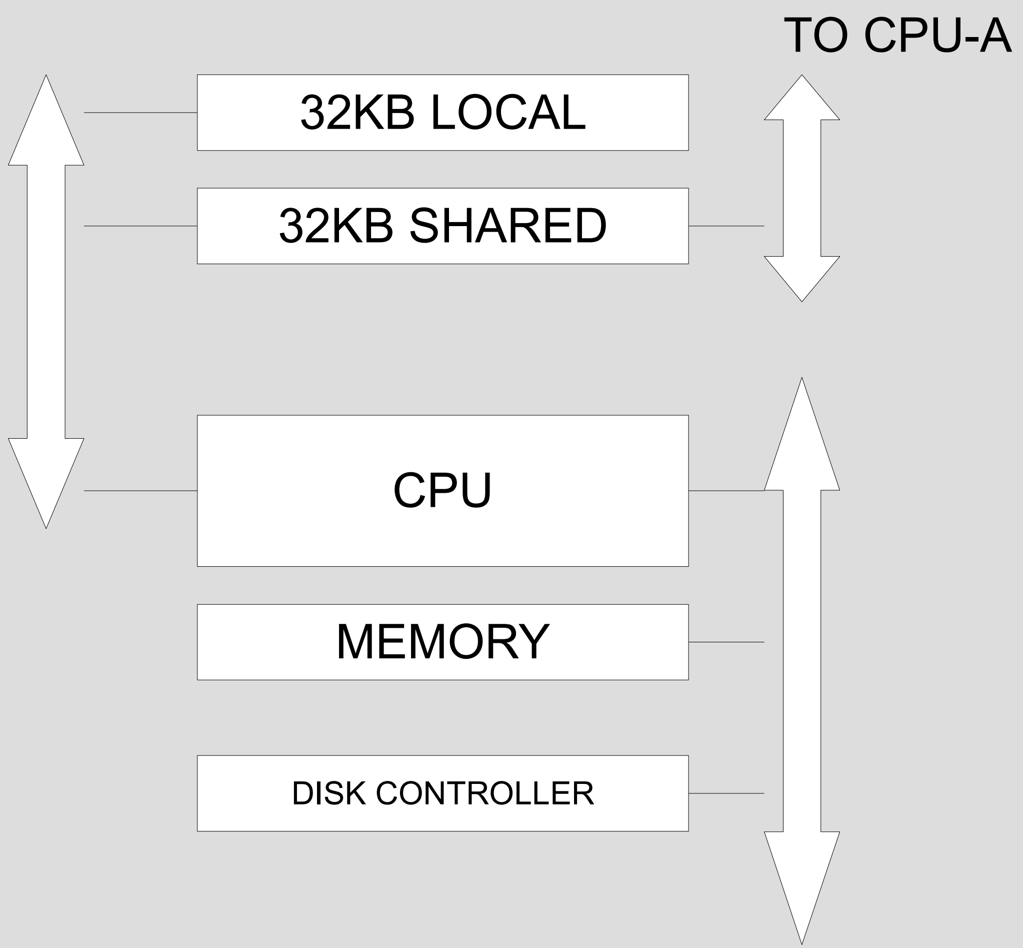
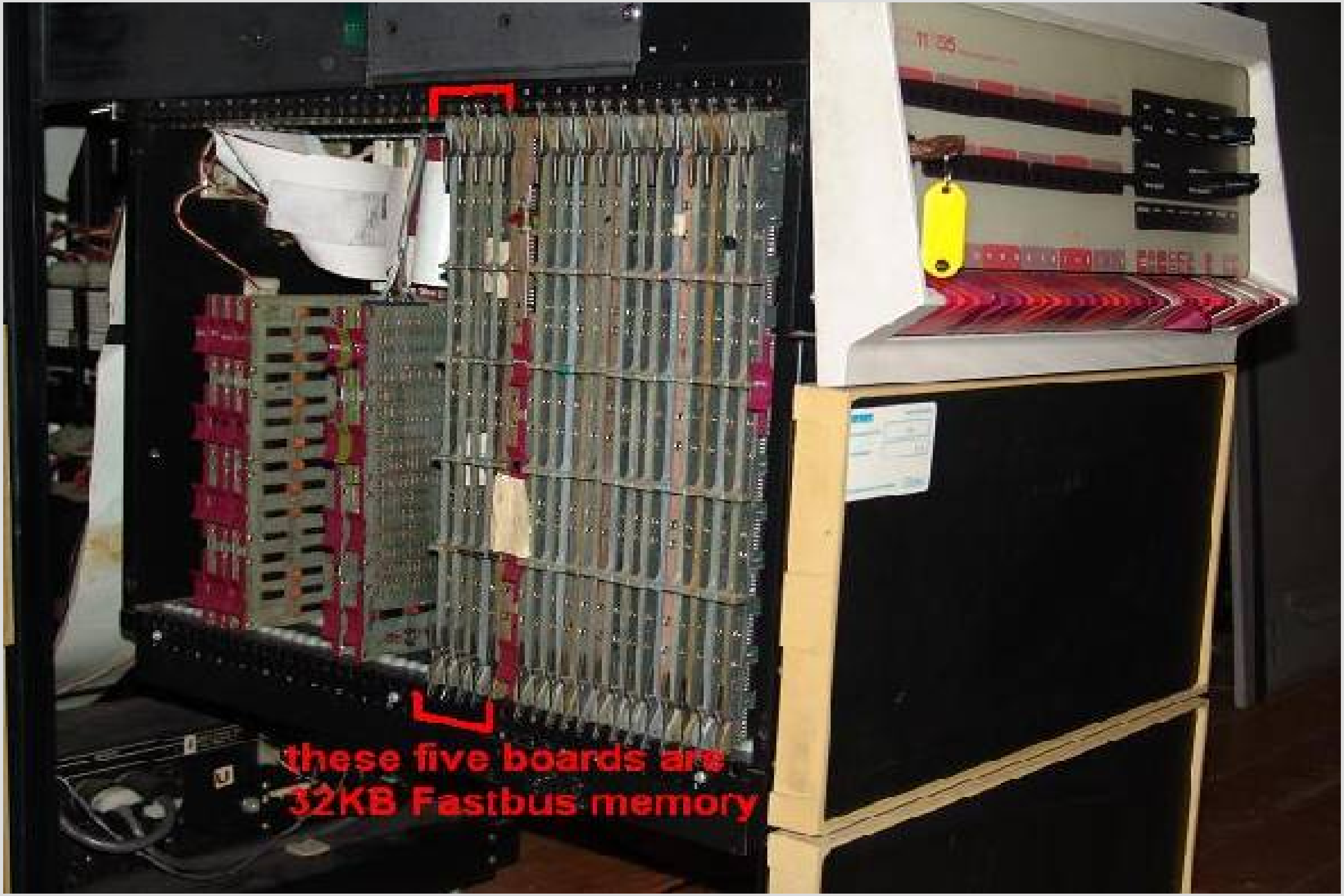
CPU-B

- **CPU-B: PDP 11/45**
  - 184KB memory
  - Plus 2 sets of 32KB Fastbus memory.
    - One shared with CPU-A
    - The other used to boost math routines
  - 2½ MB disk
  - Three busses



The Fastbus Memory



CPU-A

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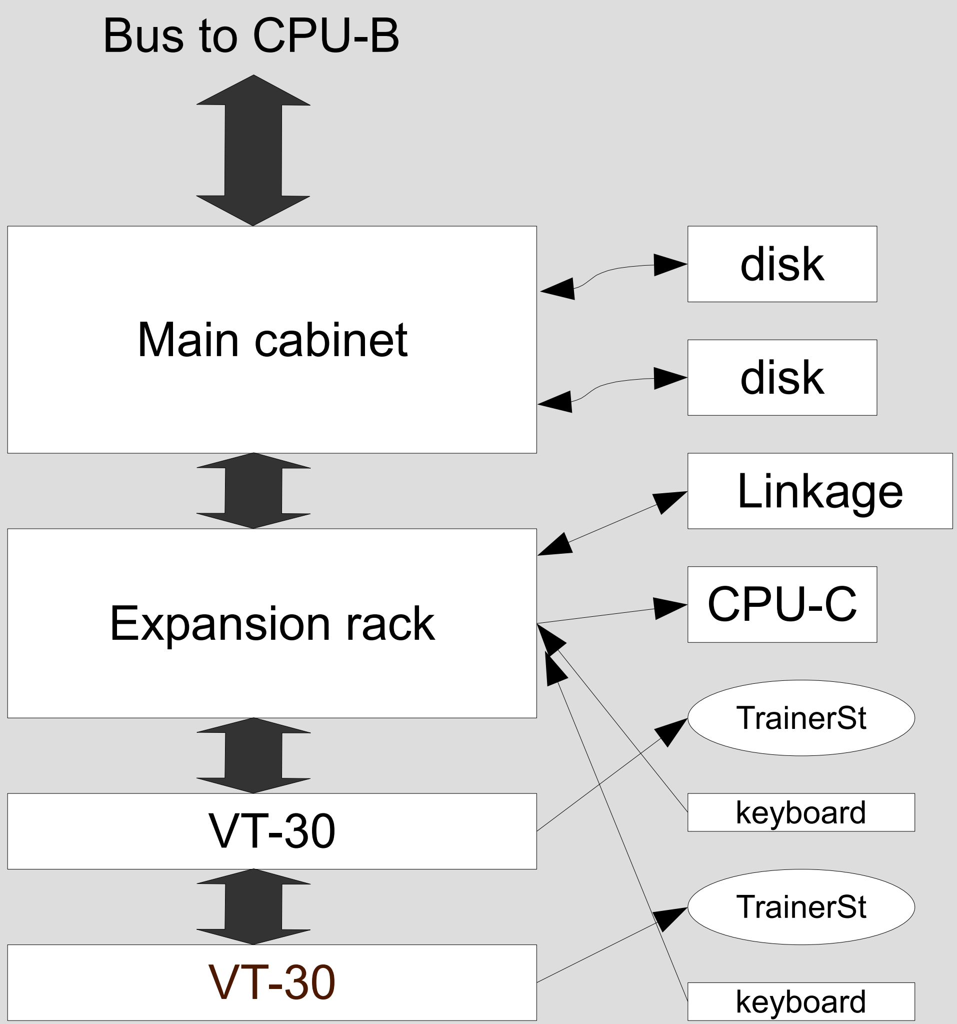
- **CPU-A: PDP 11/45**
  - 160KB memory
  - Plus 32KB shared in CPU-B.
  - 2x disks of 2½ MB
  - fast parallel I/F
  - slow parallel I/F
  - 2x VT30 graphical processors
  - Serial cards
  - Bus repeater



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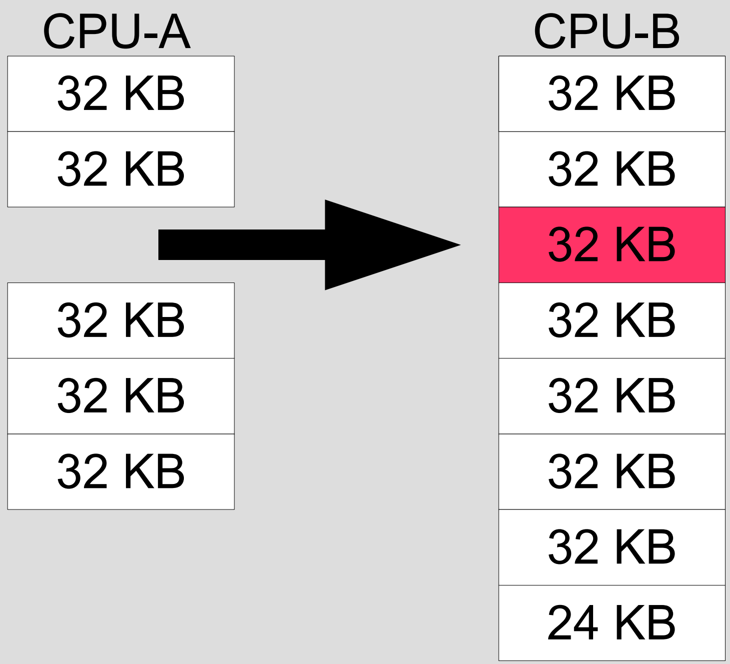
How does CPU-A look?

A and B share 32KByte of memory

- **Memory in A has a "gap"**
- **Building blocks of 32 Kbyte (not *possible in later PDP-11s)***

- **Address range of shared memory is at 200000 – 277777**



Innovations done by Continental

- Replaced core memories (4 boards per 32KB) by single board MOS memories. Created gaps by removing rows of ICs.
- Phased out most RK05 disk drives as they require regular maintenance (replacing clean-air filters twice a year).
- Replaced by Wilson Labs RK05 emulation on ZIP cartridges (hardware compatible)

- (*O.S.*, RT-11 v2, *only supports old type diskdrives*)

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1st visit: January 2008

- A: only stable for a day or two.
- B: not working.
- C: stable, can boot and passed diagnostics.
- Some 60Hz to 50Hz issues solved.
- Scrapped the 4th machine for spare parts.

- Spare parts are insufficient to keep 3 machines alive.
- Doubts about disks (Wilson ZIP drives).

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Trouble Shooting

- *If it had worked yesterday, you may expect a single problem.* Not in this case!
  - Pre-1980 hardware: simple TTL circuitry, but lot of boards in a backplane; no self-tests.
  - Power- and bus-cables are *aging*.
  - Backplane connection and contact problems.
- Strip the machine to bare CPU + Memory.
  - *Or even without memory: run 000777 on switches*
- Building up step by step.
  - On each step: run diagnostics or test by small programs.

Trouble getting home

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Time for Homework

Plan “B” is required

- Any old PDP-11 can replace CPU-C
- No other can replace CPU-B: tied to 11/45 type.
  Shared memory is a unique feature!
- Puzzle focusses on CPU-A

Original CPU-A is critical on bus length,
timing issues all over!

A solution to CPU-A problems would be beneficial!

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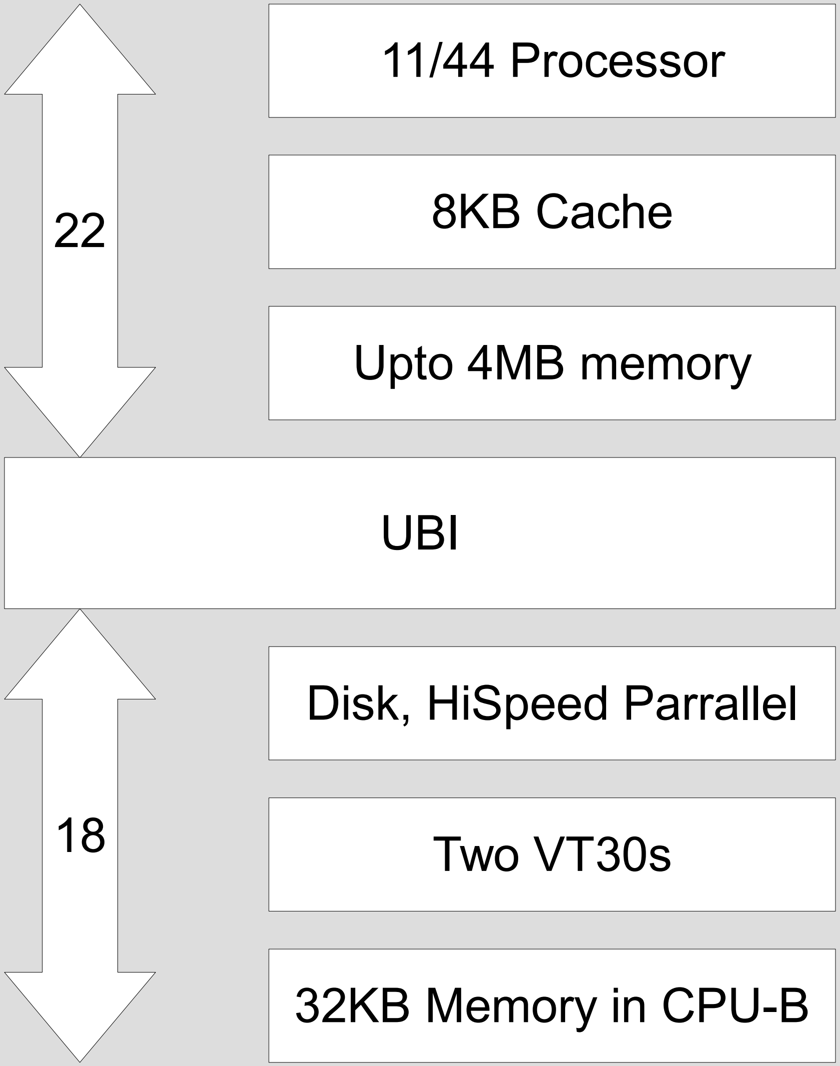
The UBI puzzle (1)

- End of February 2008: the 11/44 UniBus Interface (UBI) specification *suggests* we can “cut” a slice out of main memory by a special configuration on this board.

- Until mid of June our *proof of concept* fails as the above statement is not exactly true



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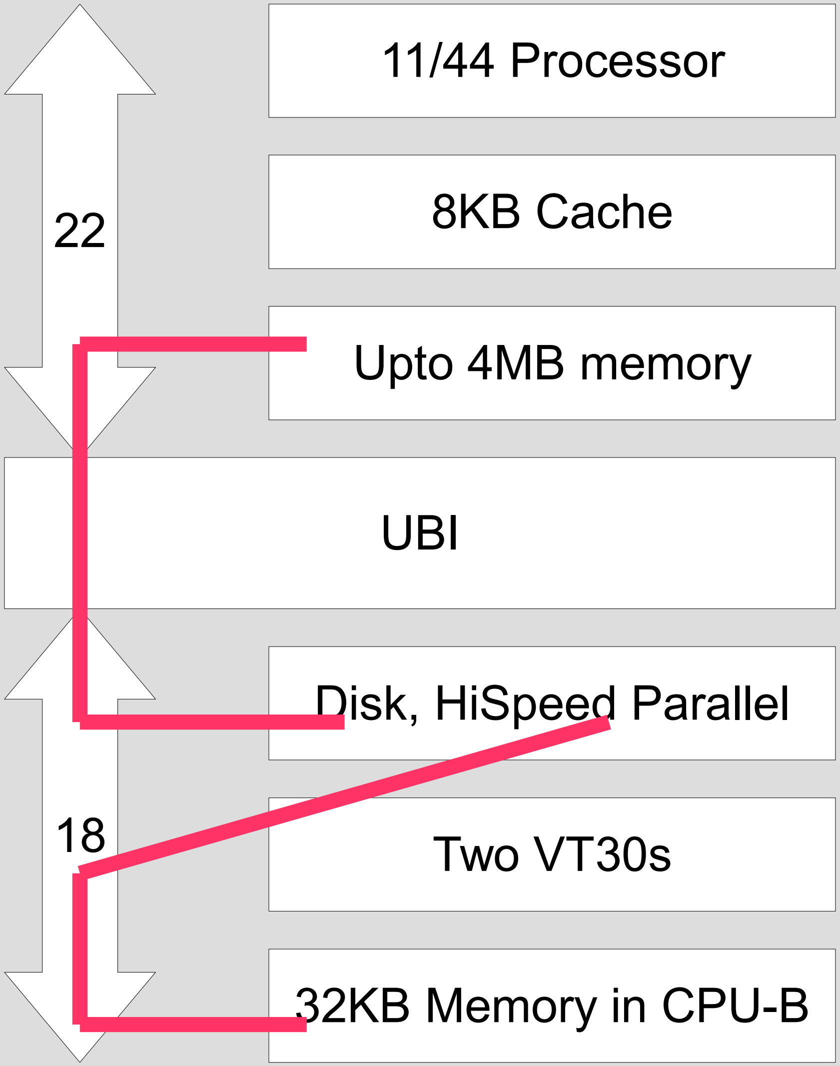
The UBI puzzle (2)

- Normal function of UBI: enable DMA controllers to do I/O to main memory beyond 18 bit limit, by mapping to 22 bit addresses.
- The special config option inhibits this mapping for a range of addresses: DMA stays on the 18 bit Unibus and targets the shared memory in CPU-B.



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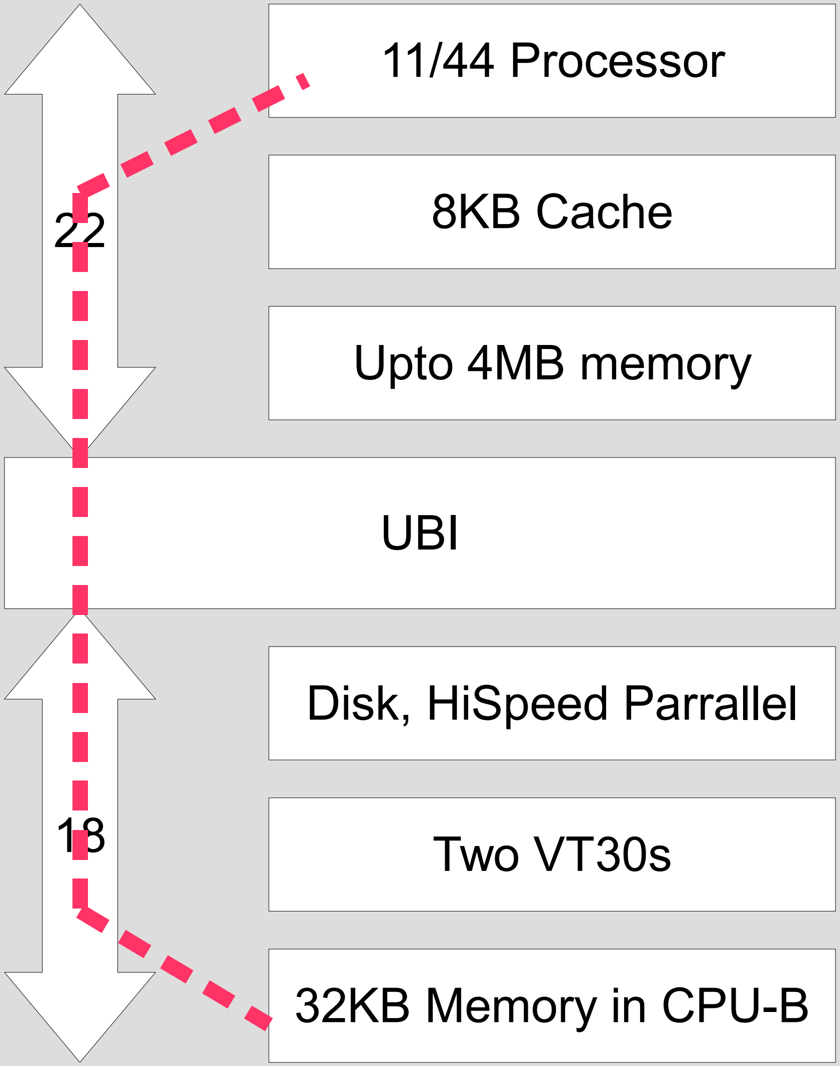
The UBI puzzle (3)

- Shared memory in CPU-B starts at physical address 200000.
  Clue: physical address in the 11/44 is 17200000 (four extra bits)
- Cache memory luckily ignores this external memory.
- *Software on CPU-A needs to be changed!!*



Jan's trip to NL by car
(July 2008)

- IN:
  - Two Wilson ZIP drives for testing + backup disks on ZIP.
  - All RK05 diskpacks with original software
- OUT:
  - Two Wilson ZIP drives, tested “OK”.
  - Two PDP 11/44s (*hard to find in this century*)
  - Spare power supply for 11/44.
  - PC to connect consoles (=serial lines) to Internet.
  - Network card, 10Mbit ethernet stuff for A or C.
    - FTP stack for latest edition RT-11: can transfer files and diskimages.
    - Latest RT-11 can run in RAM disk.
    - *connecting Island to Mainland*.

Aug/Sept 2008: digging into software

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- We now have the software:
  - 160 000 lines of PDP-11 assembler code.
  - *Hard to read and get an overview.*
- Link Miles has built multi-tasking capabilities on top of simple operating system.
  - CPULDR: loads modules into memory.
    - inits runtime MMU settings for each module.
  - LMEXEC: real time scheduler.
    - Modules are member of rating class: run a designated number of times per second.
    - Sets MMU when switching from one module to another.
- Changes focus on CPULDR

CPULDR

- Original: 3698 lines of code; *comments* are significant while reading.
- Changes:
  - Settings of MMU registers (PAR, Page Address Register)
    - pointing to Shared Memory
    - pointing to Device Area (top 8KB)
  - Enabling 22 bit mode (medium to large machine)
  - Loading of data into Shared Memory
  - *Total of 15 (small) changes required*
- Development done using SimH emulator running on Windows: a disk = a file.

Testing with SimH (1)

- Obviously, stops as soon as software touches hardware that is not present.
- SimH is much faster than any real PDP-11

- Three new loaders :
  - T44LDR relocating to area up in 1MB, for testing only.
  - A44LDR intended loader for CPU-A.
    - Cannot test without the hardware: adapted from T44LDR.
  - F44LDR: loads all modules A + B.
    - Full Function on a single machine.
    - Loads correctly. Never got alive, possibly caused by incomplete initialisations.

- “GO” for replacing CPU-A by 11/44

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Testing with SimH (2)

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```
?M-TRAP TO 4 022266
!
Simulation stopped, PC: 111750 (TST (R5)+)
sim> e 200000
200000: 001766
sim> do kpars
17772340:       000000
17772342:       000200
17772344:       000400
17772346:       000600
17772350:       001000
17772352:       001200
17772354:       002000
17772356:       007600
sim> do spars
17772240:       002200
17772242:       002024
17772244:       003400
17772246:       003000
17772250:       003200
17772252:       001200
17772254:       002000
17772256:       007600
sim> do upars
17777640:       002200
17777642:       000200
17777644:       002000
17777646:       000600
17777650:       001000
17777652:       001200
17777654:       002000
17777656:       001600
sim>
```

```
?M-TRAP TO 4 022310
!
Simulation stopped, PC: 116244 (
sim> e 200000
200000: 000000
sim> e 3200000
3200000:        001766
sim> do kpars
17772340:       000000
17772342:       000200
17772344:       000400
17772346:       000600
17772350:       001000
17772352:       001200
17772354:       032000
17772356:       177600
sim> do spars
17772240:       032200
17772242:       002024
17772244:       003400
17772246:       003000
17772250:       003200
17772252:       001200
17772254:       032000
17772256:       177600
sim> do upars
17777640:       032200
17777642:       000200
17777644:       032000
17777646:       000600
17777650:       001000
17777652:       001200
17777654:       032000
17777656:       001600
sim>
```

2nd visit: October 2008

- Installed CPU-A NG: 11/44
  - All in a single box
  - No bus repeater required
  - Bus tested OK

- Installed CPU-C NG: 11/44

- Old CPU-C as new CPU-B
  - Installed MMU option: upgrade small to medium.
  - Fastbus Memory did not work!!

- Installed Unix PC and local network
- Taken all Fastbus memory home for testing.

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What is Linkage?

- A modular set of hardware to interface everything in the cockpit to a fast I/O interface.
  - One mastercontroller connected to CPU-A
  - Own bus with three subcontrollers
  - A large set of various types of interfaces:
    - Low and High voltage in/out
    - Digital in/out
- Config depends on cockpit/aircraft type
- I/O is done 20 times per second

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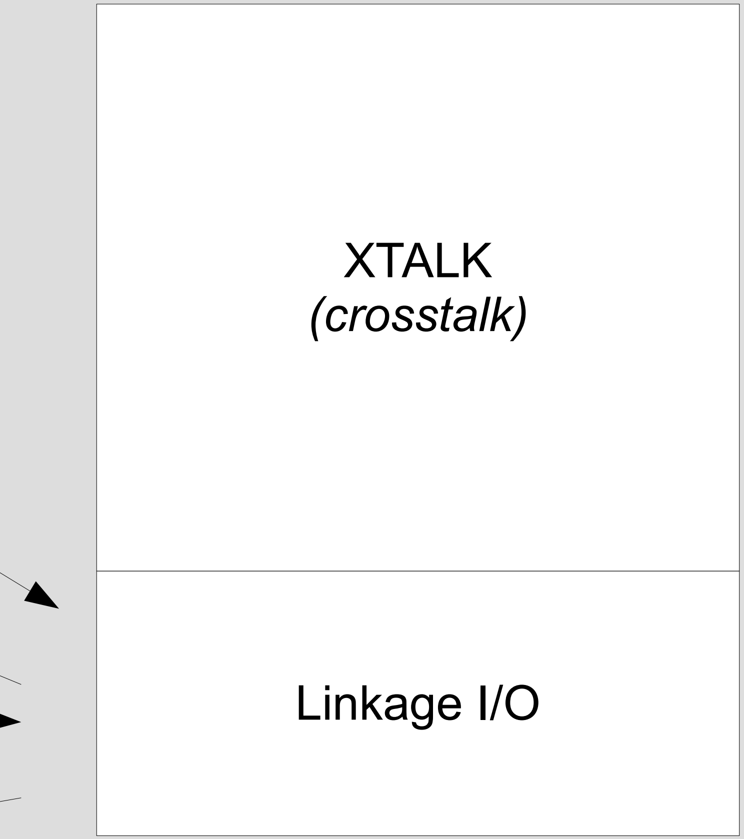
Where does Linkage I/O end?

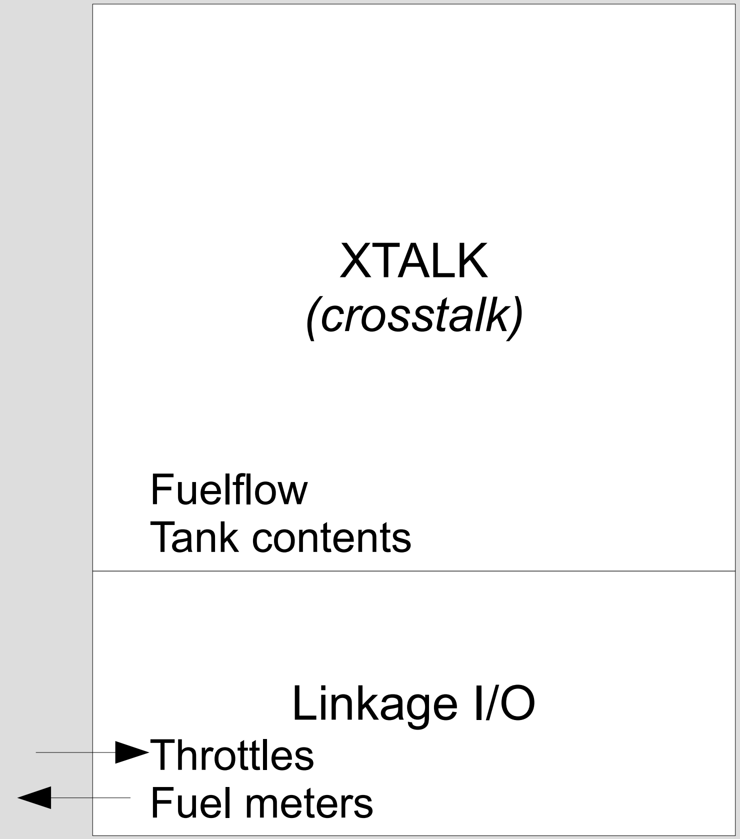
- In Shared Memory:
  - Digital IN
    288 bytes
  - Digital OUT
    320 bytes
  - Analogue IN
    288 bytes
  - Analogue OUT
    760 bytes



What's in XTALK?

All global variables for all software modules.

- <u>Module “Engines” (EN)</u>: fuelflow triggered by throttles.
- <u>Module “Fuel” (SF)</u>: contents of tanks decreased by fuelflow. Outgoing data to fuel indicators.



Winter '08-'09

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- Special setting UBI undone: using standard loader and F44LDR in single CPU mode
- No signs of life: *still looking into darkness*
- Jan c.s. found broken cables in Linkage

- April '09: Analogue-IN shows moving throttles and more of that kind.
- Fastbus Memories tested and bit errors repaired by replacing I.C.s.
- Test program made to read Linkage.
- Monitoring Linkage shows huge instability

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3rd visit: June 2009

- Diagnosed ground-loop in Linkage system (repair done later)
- Old CPU-C has a backplane problem preventing Fastbus Memory to work.

- Old CPU-B with board-set of old spare machine works fine, including the Fastbus Memory (shared set only).

- *Configuration complete… but still not alive!*

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Digging very deeply

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Final preflight...

- Accidently discovered CPU-C has to run.
- Ground loop fixed by Jan c.s.: Linkage tested and now stable.
- Runs for 30 seconds: ends in *CPU LATE*
- Suspected CPU-A but discussion with Derek pointed to CPU-B.
- August 3: tried to install second set Fastbus memory (booster for math routines)
- Did a software workaround on B.

- *August 20: first “flight” of 35 minutes*.

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Special Thanks

Feedback is writing down your story and getting encouragement, a comment or a hint. (*not always answers on your questions*)

- Dan, Martin, Wilber former |d|i|g|i|t|a|l|
- Nick, Dag, at Continental Airlines
- Steve, Peter and last but not least Derek former Link Miles employees.

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A thought at last...

If it works

Plug 'n Play

you don't learn anything.

We have learned a lot.

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Pointers

- www.bejaardecomputers.nl
  - Geert.Rolf@xs4all.nl

- www.dc10.no

- www.link-miles.co.uk