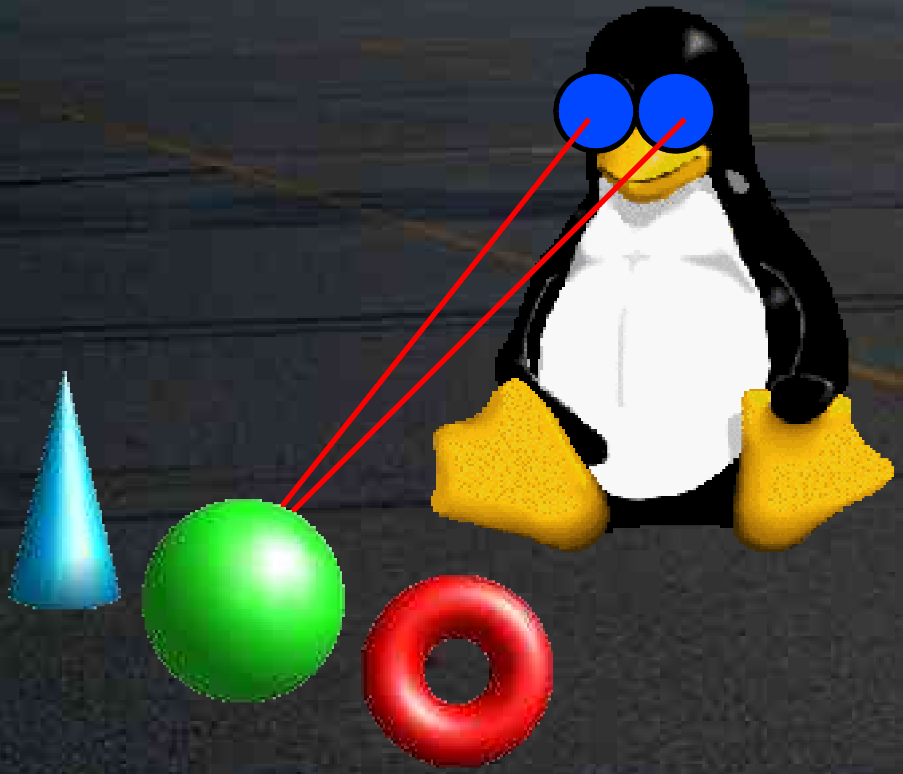
Building User Interfaces With Video and 3D Graphics For Fun and Profit!

Tutorial Presentation

Linux Conf Au – Canberra ACT

April 2005



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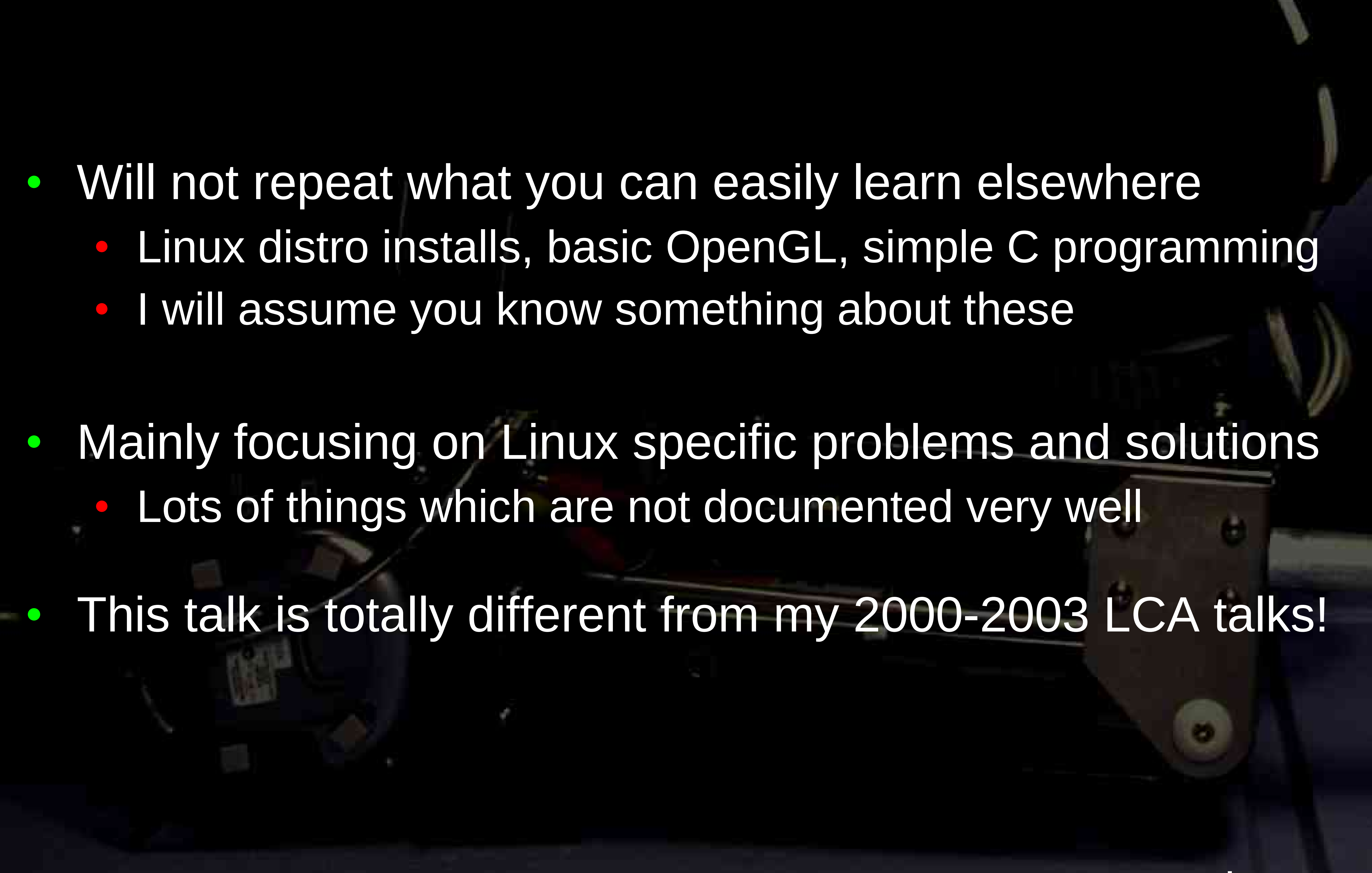
What is this tutorial about?

- Brief introduction to 3D, virtual and augmented reality
- OpenGL and live video display under X11
- Video capture using Video4Linux and Firewire
- 3D vision tracking using ARToolKit and OpenCV
- Custom hardware input devices
- Demos of Tinmith backpack

- Show you the kinds of cool applications you can build at home without having to spend a lot of money!

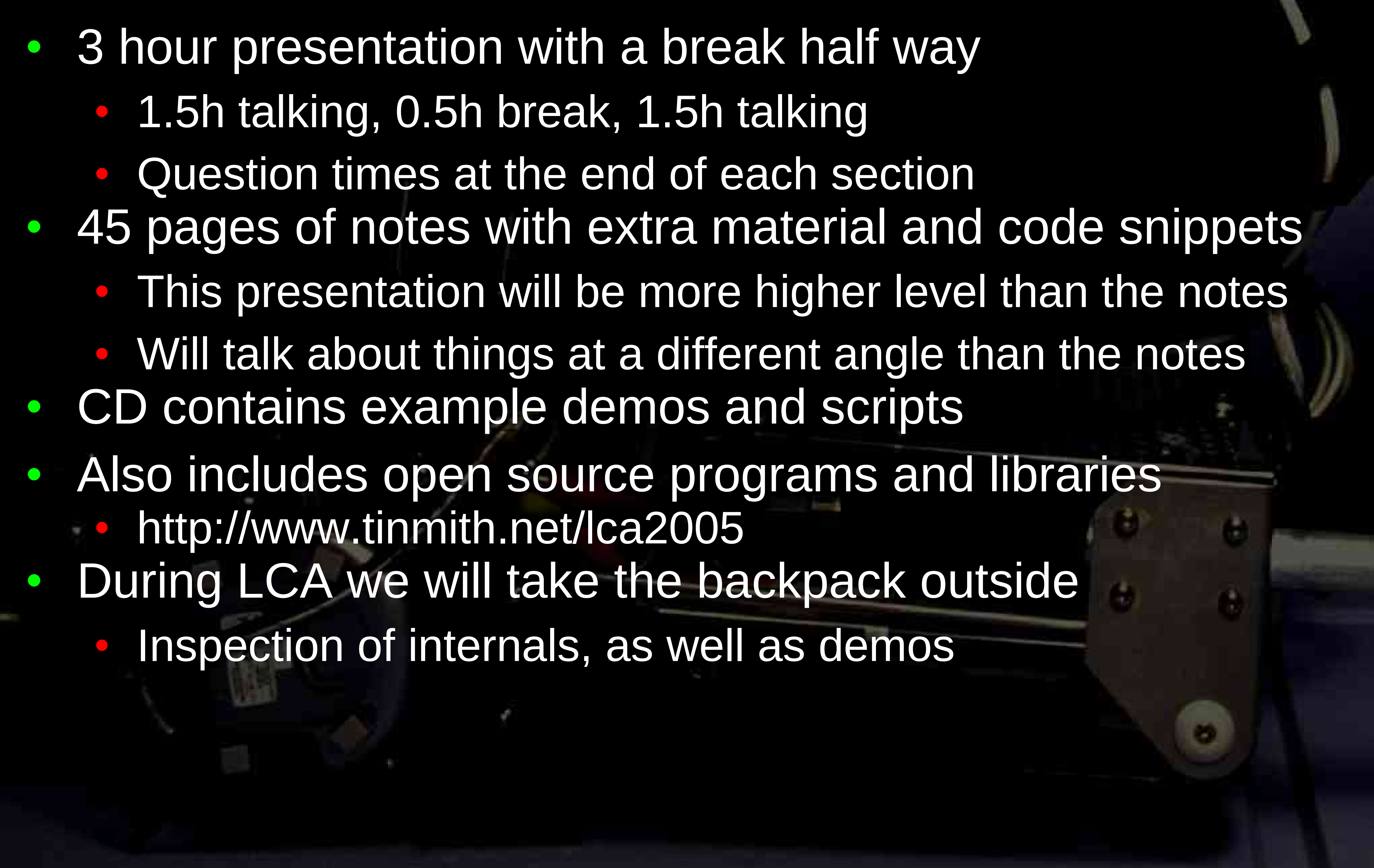
What is this tutorial not about?



- Will not repeat what you can easily learn elsewhere
  - Linux distro installs, basic OpenGL, simple C programming
  - I will assume you know something about these
- Mainly focusing on Linux specific problems and solutions
  - Lots of things which are not documented very well
- This talk is totally different from my 2000-2003 LCA talks!

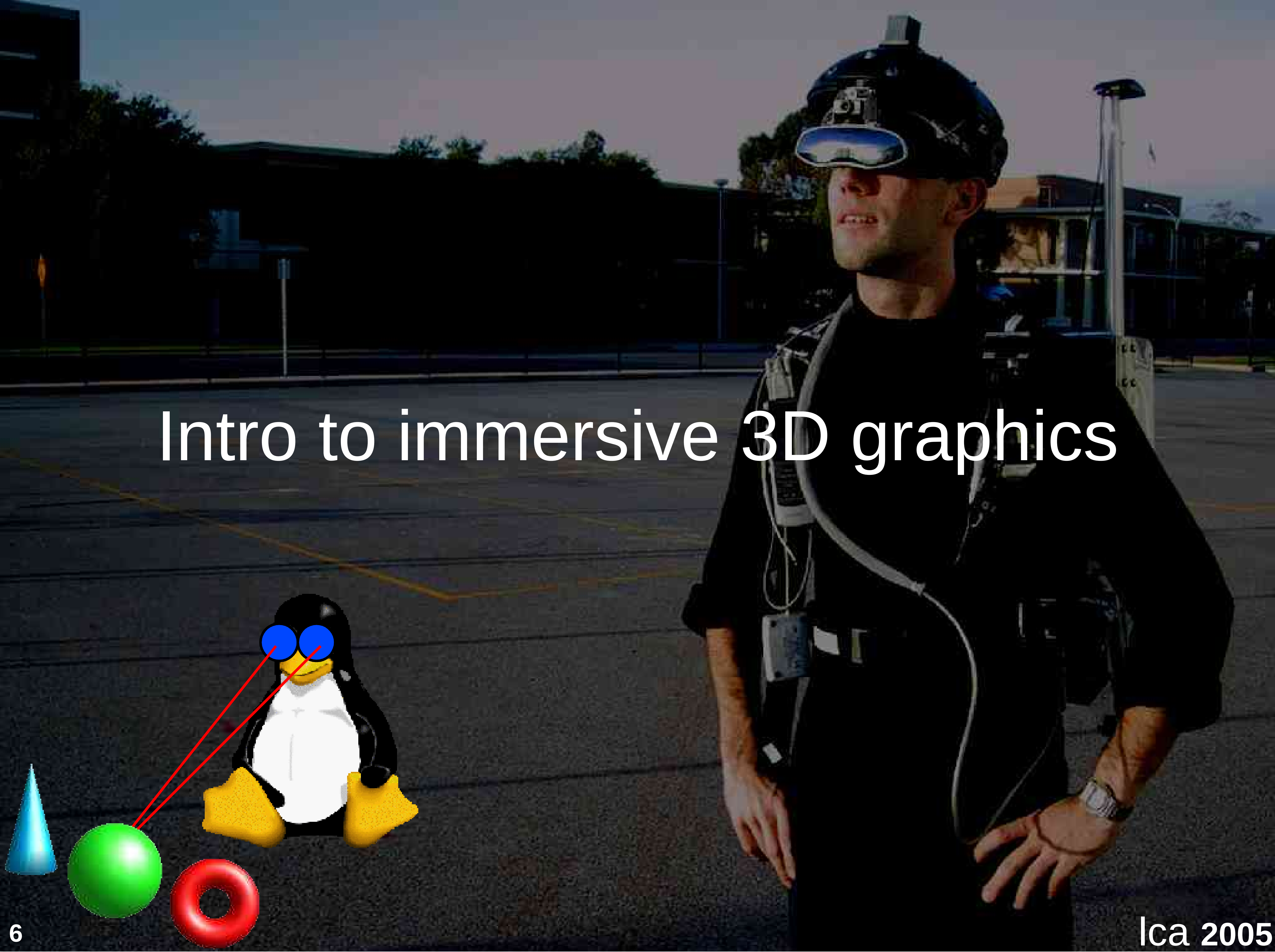
Tutorial and supplied materials

- 3 hour presentation with a break half way
  - 1.5h talking, 0.5h break, 1.5h talking
  - Question times at the end of each section
- 45 pages of notes with extra material and code snippets
  - This presentation will be more higher level than the notes
  - Will talk about things at a different angle than the notes
- CD contains example demos and scripts
- Also includes open source programs and libraries
  - http://www.tinmith.net/lca2005
- During LCA we will take the backpack outside
  - Inspection of internals, as well as demos



Lazy like a fox

- Teach you interesting things you can do at home to hack around with 3D right now!
- Lots of projects, not enough time to work on them
- Focus is on areas that are poorly documented or difficult to play around with due to complexity
- Tricks to build things on the cheap
- http://www.tinmith.net/lca2005



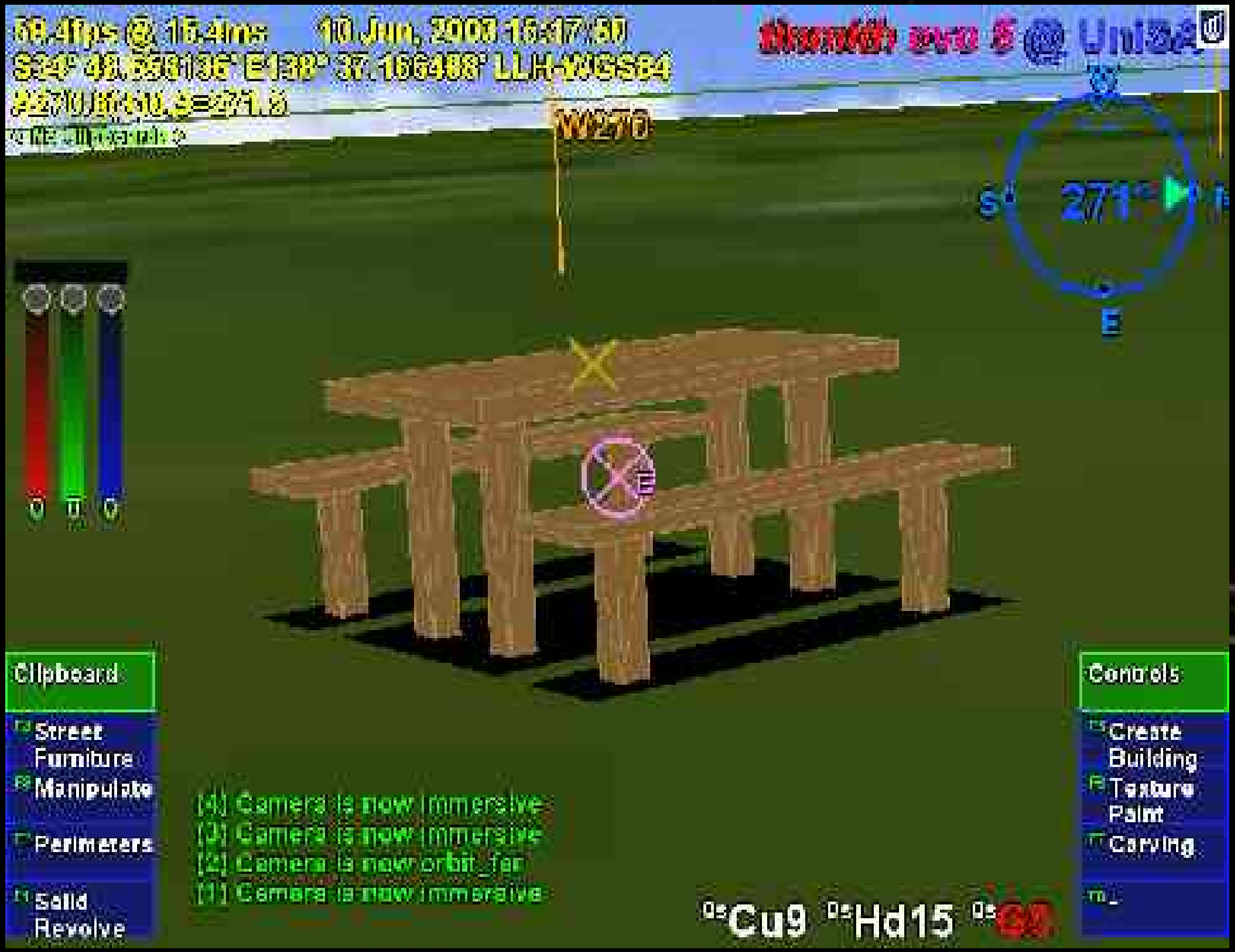
Intro to immersive 3D graphics

Immersive 3D graphics

- My research work focuses on immersive 3D applications
- I typically use a head mounted display
  - There are plenty of things we can do on a monitor though!

Virtual and augmented reality

- Virtual reality is purely computer generated graphics
- Augmented reality combines the physical world with artificial computer graphics



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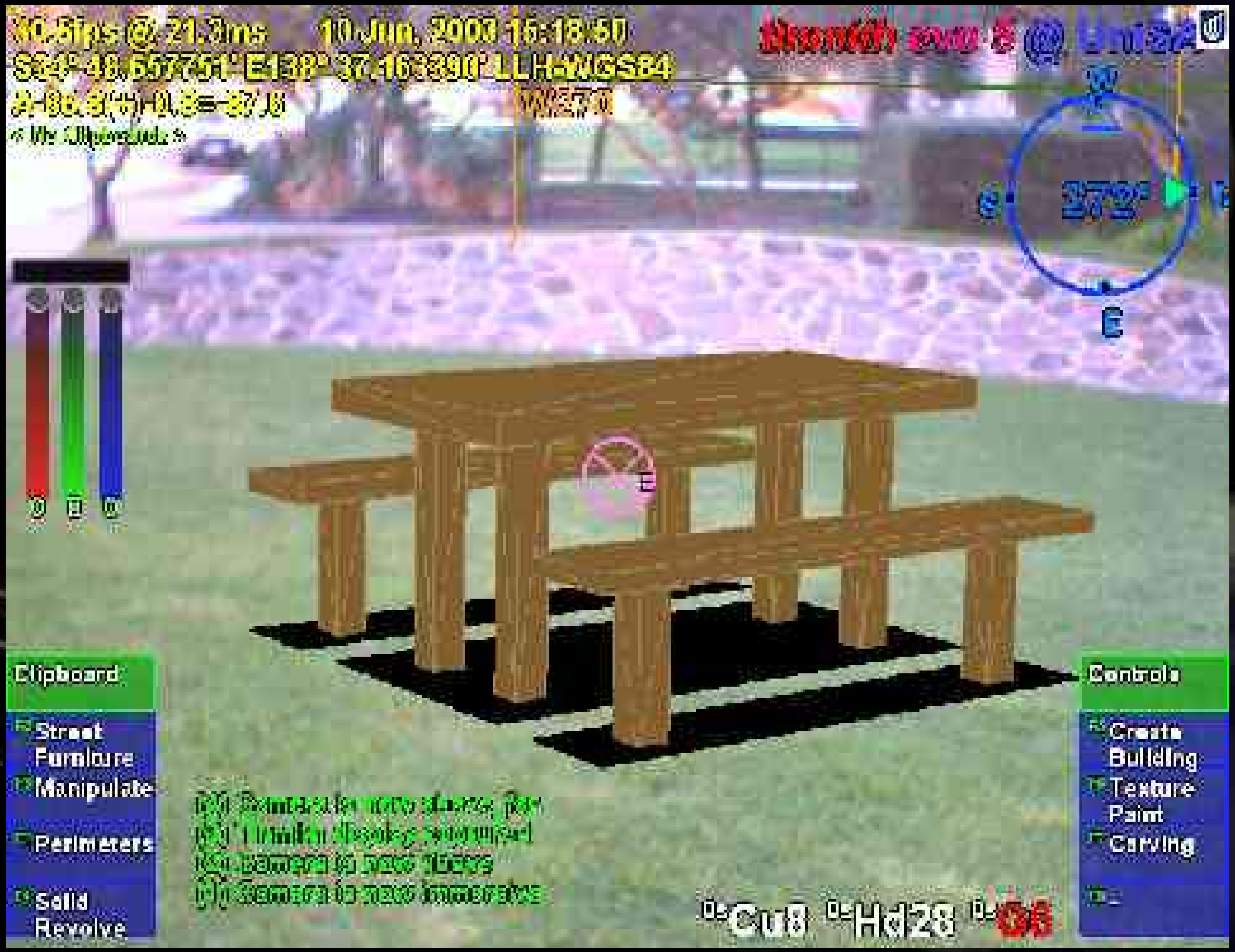
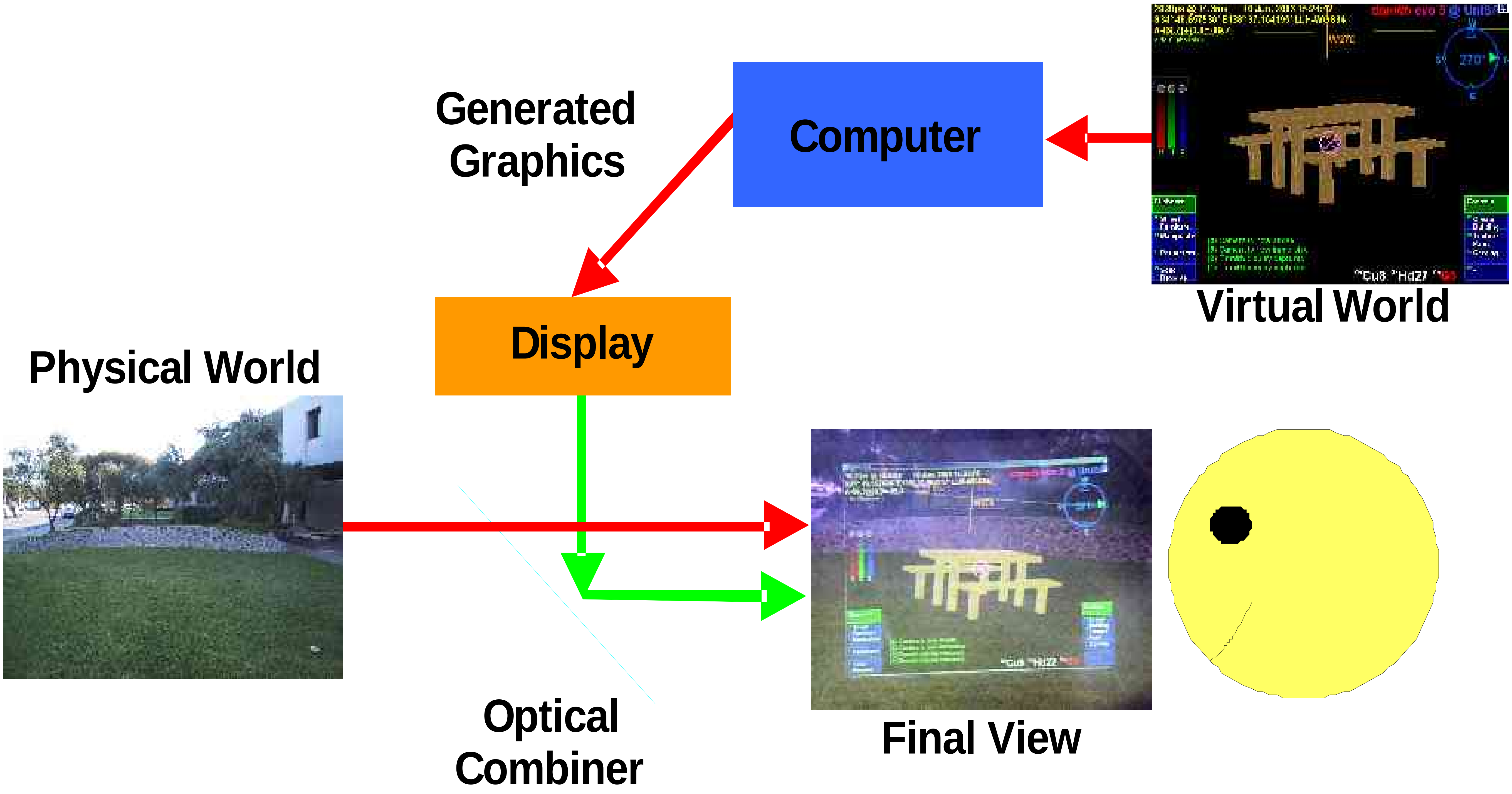


[1] Camera is now immersive

Optical augmented reality

- Hard to find these displays for a reasonable price now



Generated Graphics

Computer

Virtual World

Display

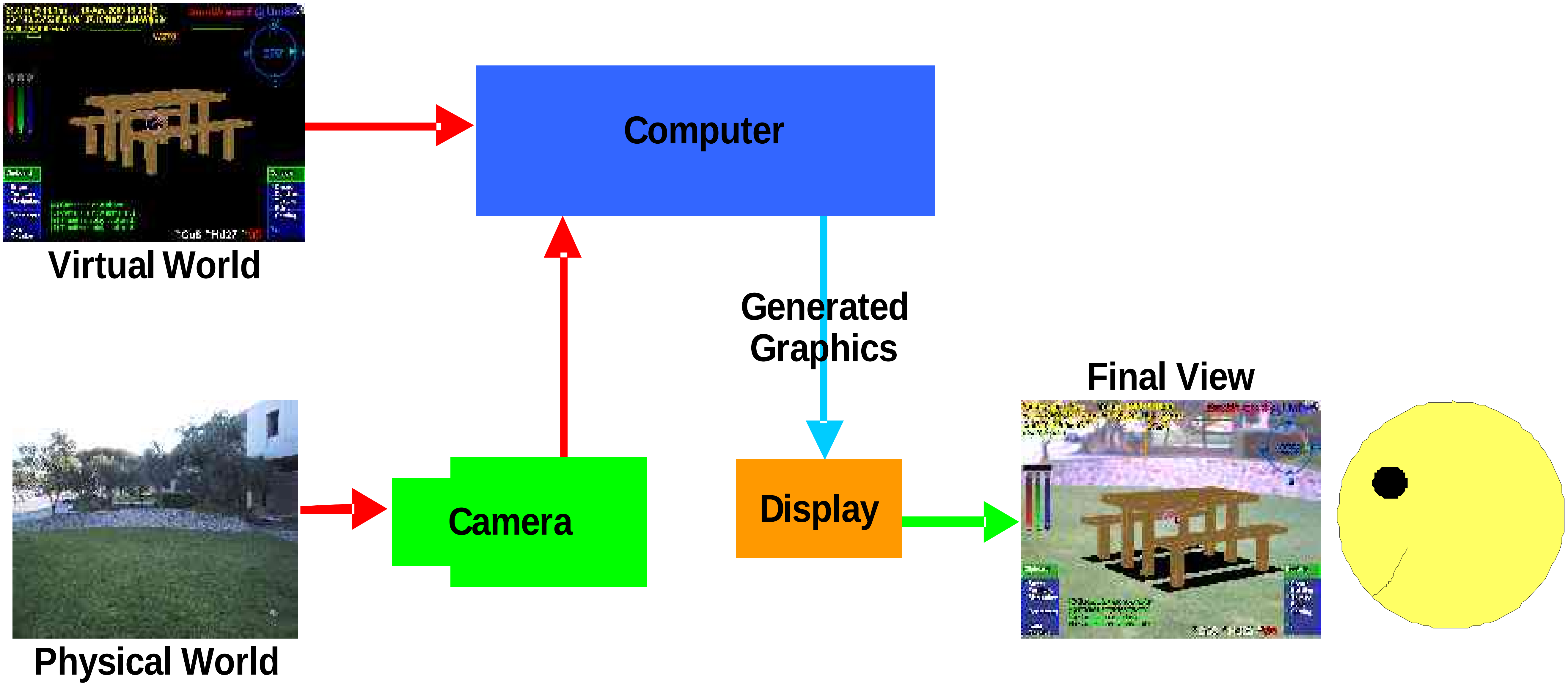
Physical World

Optical Combiner

Final View

Video augmented reality

- Displays from VR can be used with no modifications
- We use these displays almost exclusively now
  - Cheaper and easier to buy, better quality output



Virtual World

Computer

Generated Graphics

Physical World

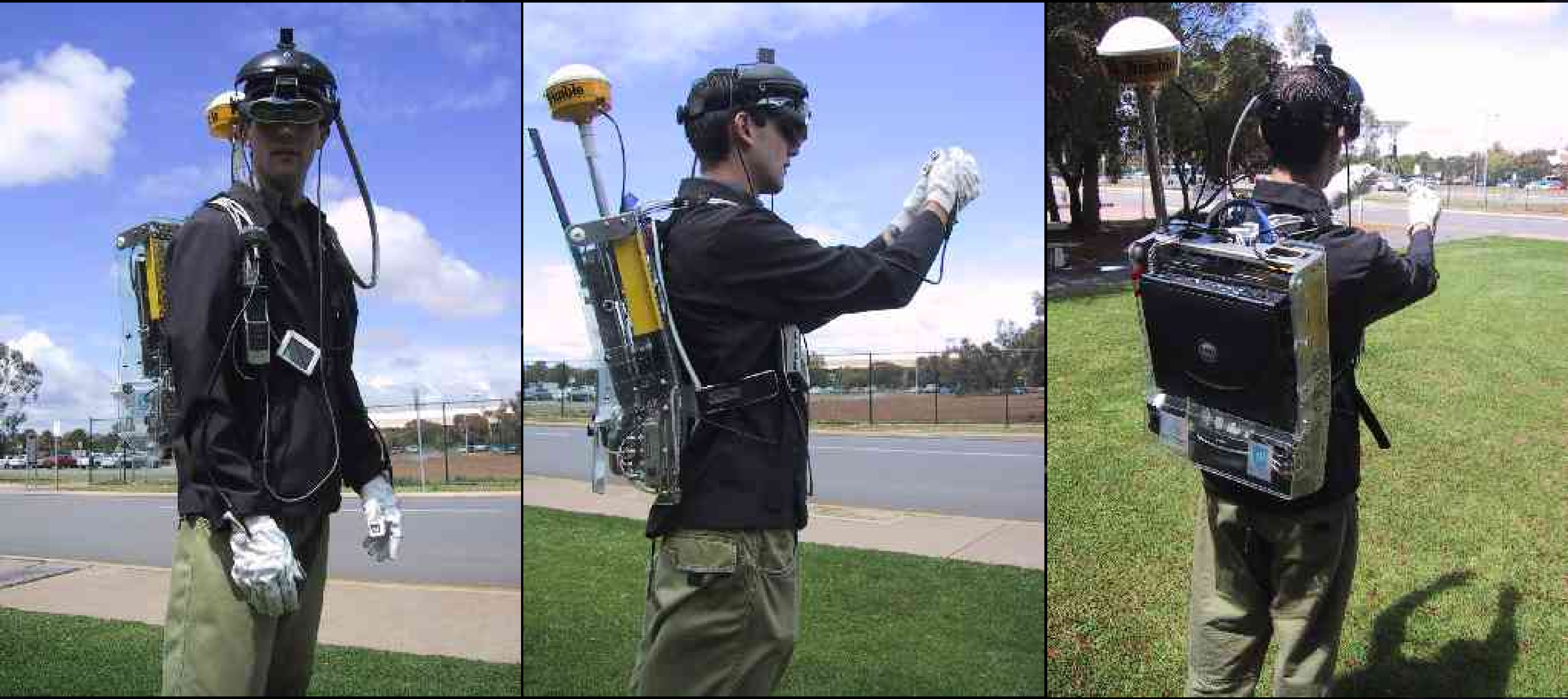
Camera

Display

Final View

Outdoor augmented reality

- My research work focuses on performing AR outdoors
- Especially mobile 3D user interfaces and modelling

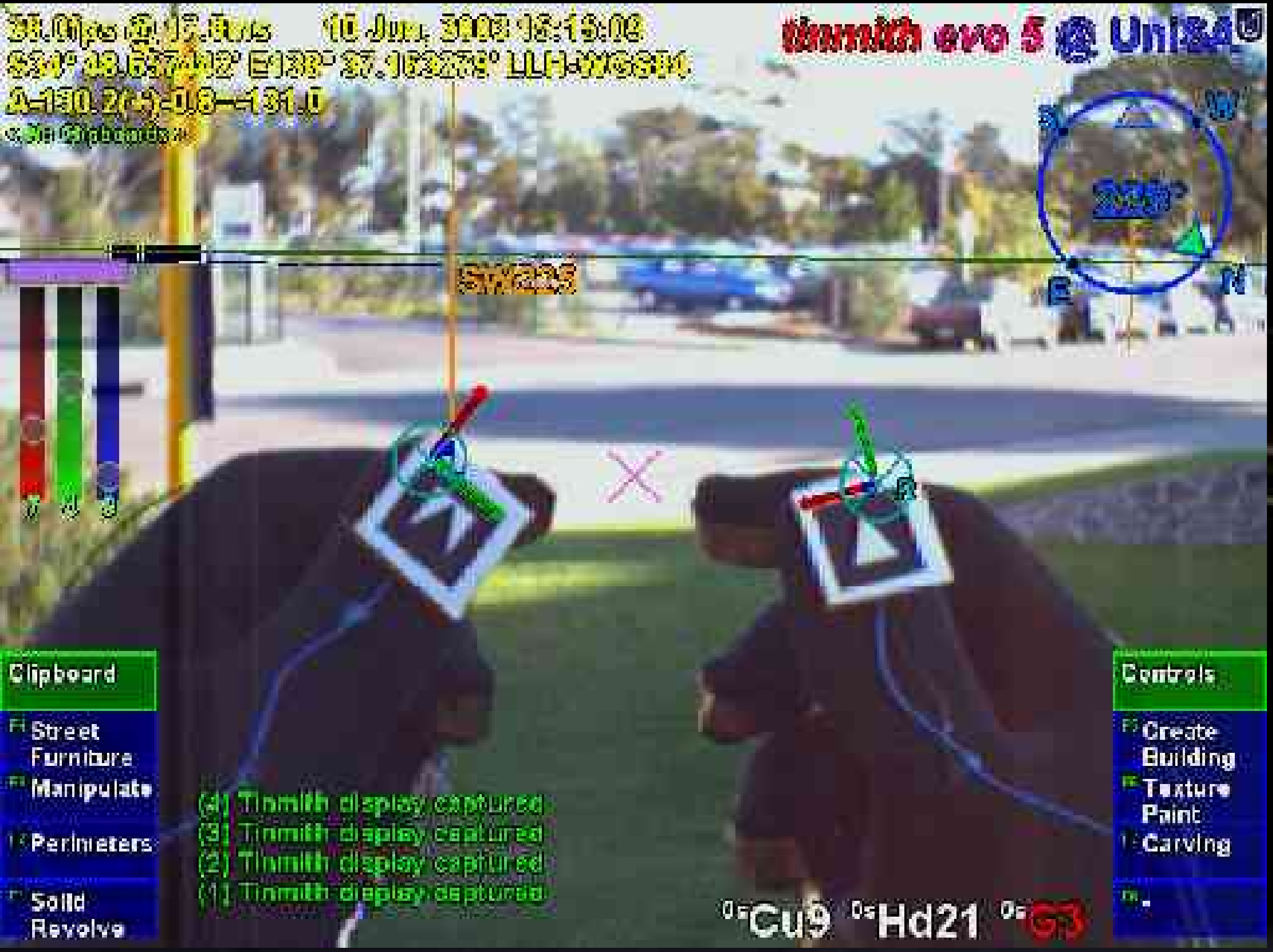


3D compared to 2D

- 3D is much more challenging than 2D
  - More degrees of freedom and more input devices
  - More realistic and intuitive application possibilities
  - Potential to use the body directly
- Don’t use 2D input devices
  to solve a 3D task!

Tinmith mobile 3D modelling

- Gloves are used to control the environment
- User interface designed specifically for mobile AR
- Supports outdoor modelling and editing applications



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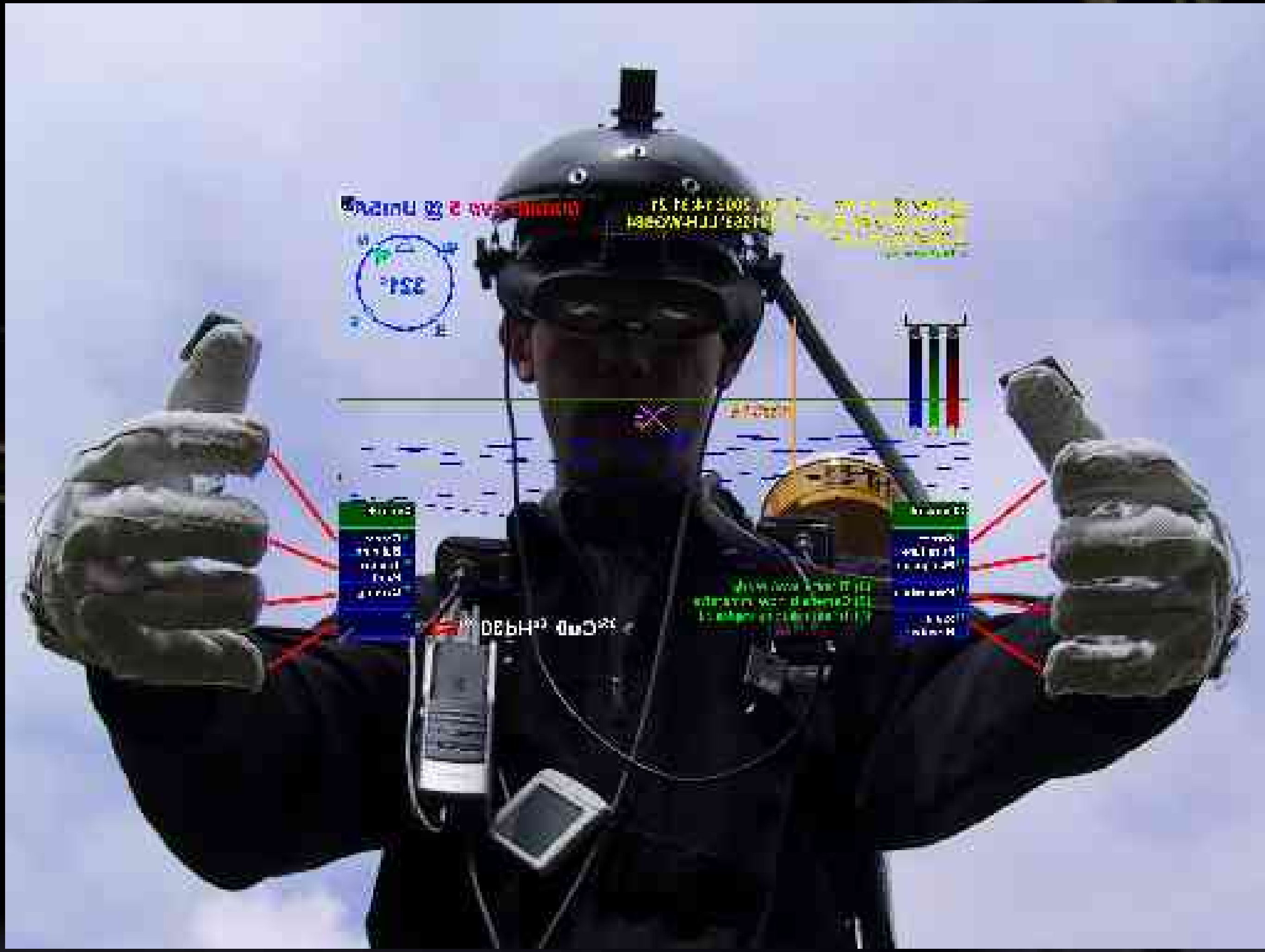
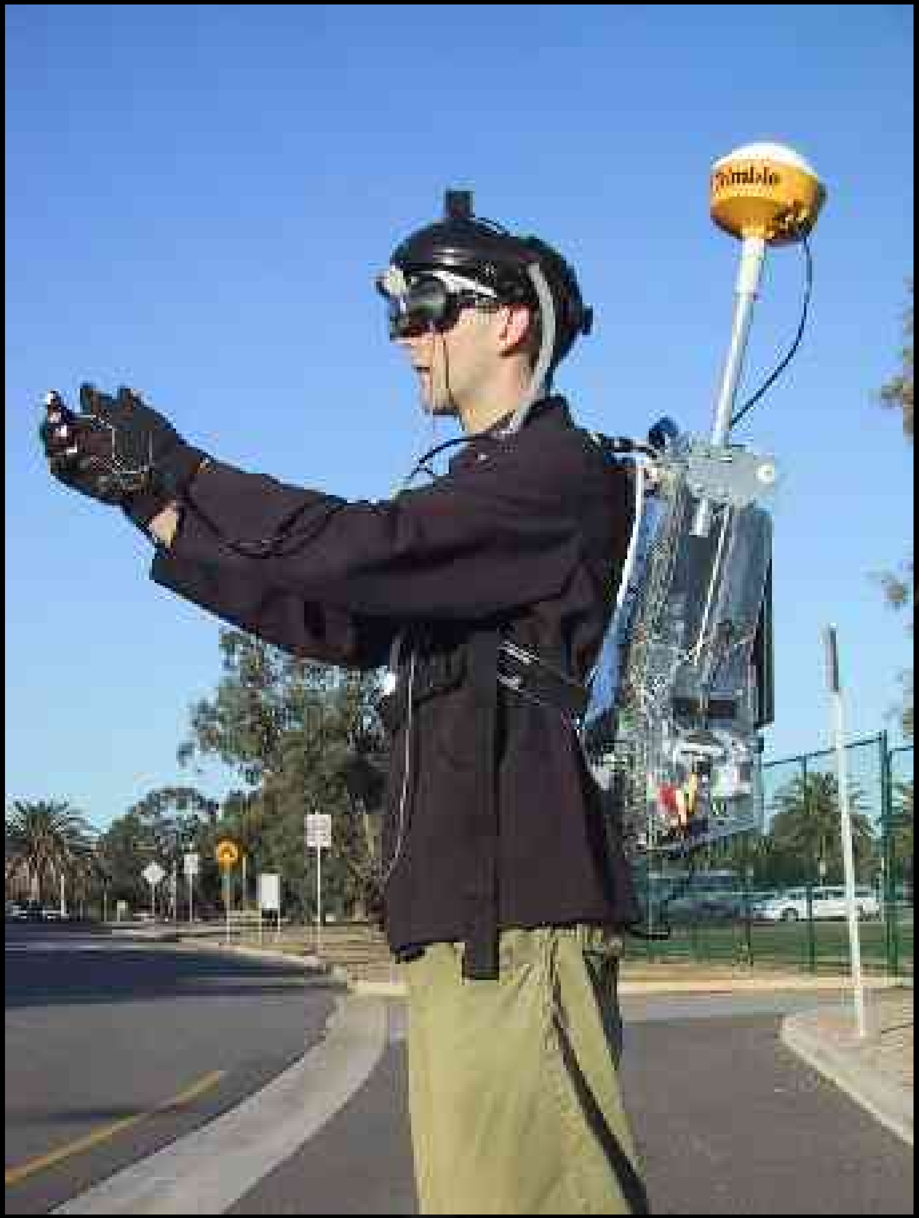
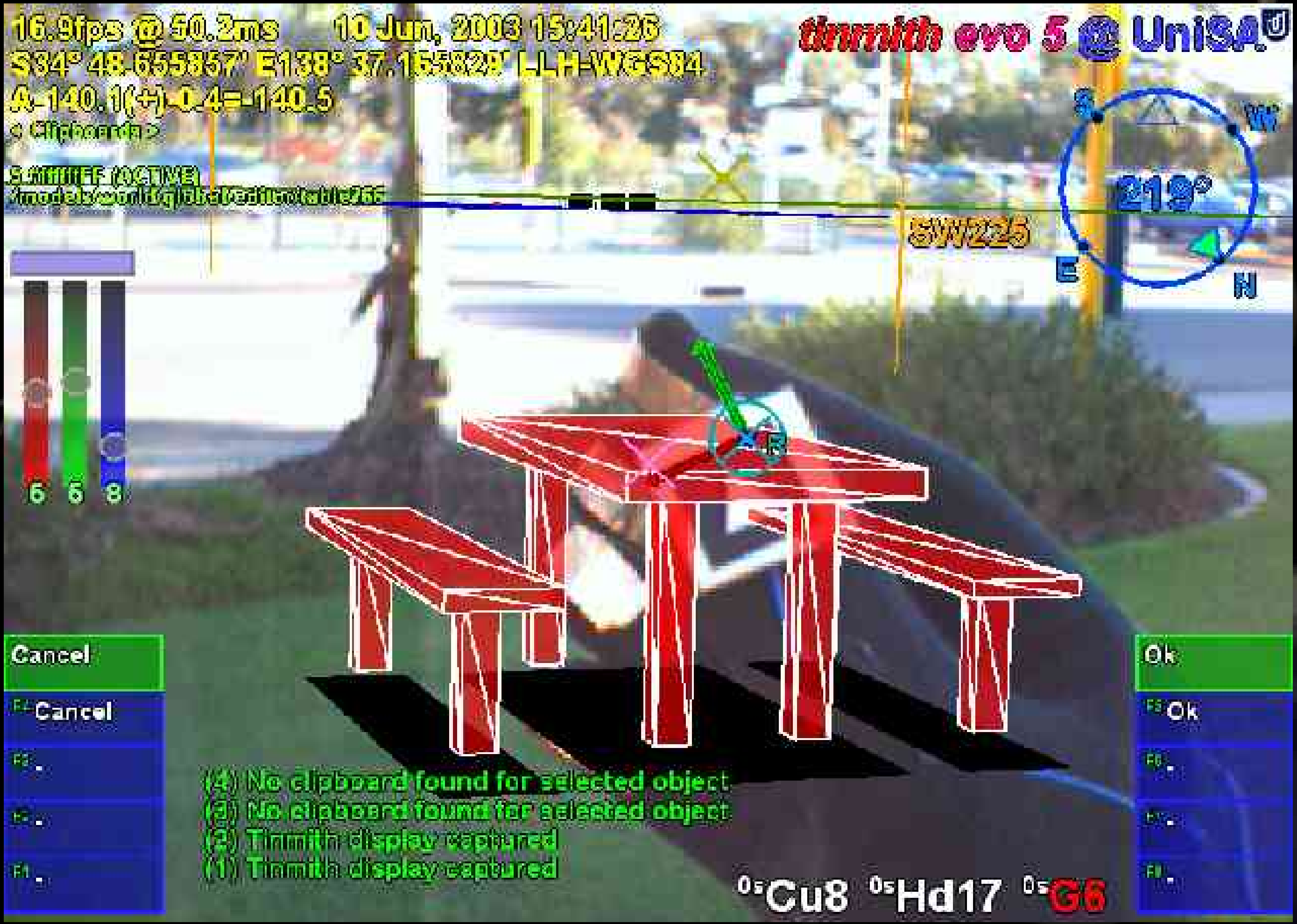


User interface demonstration

- Play UI demo video here





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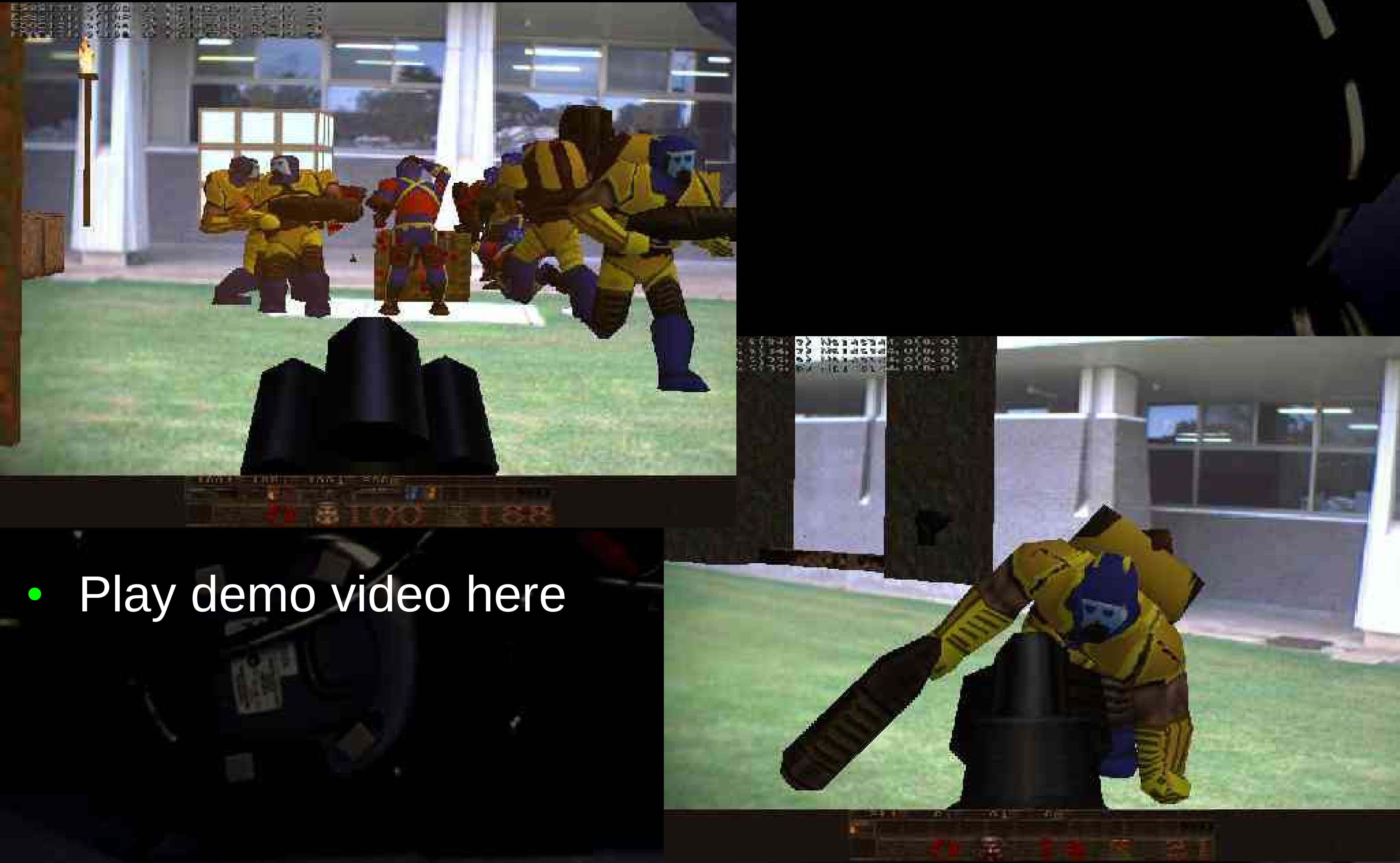
ARQuake demonstration

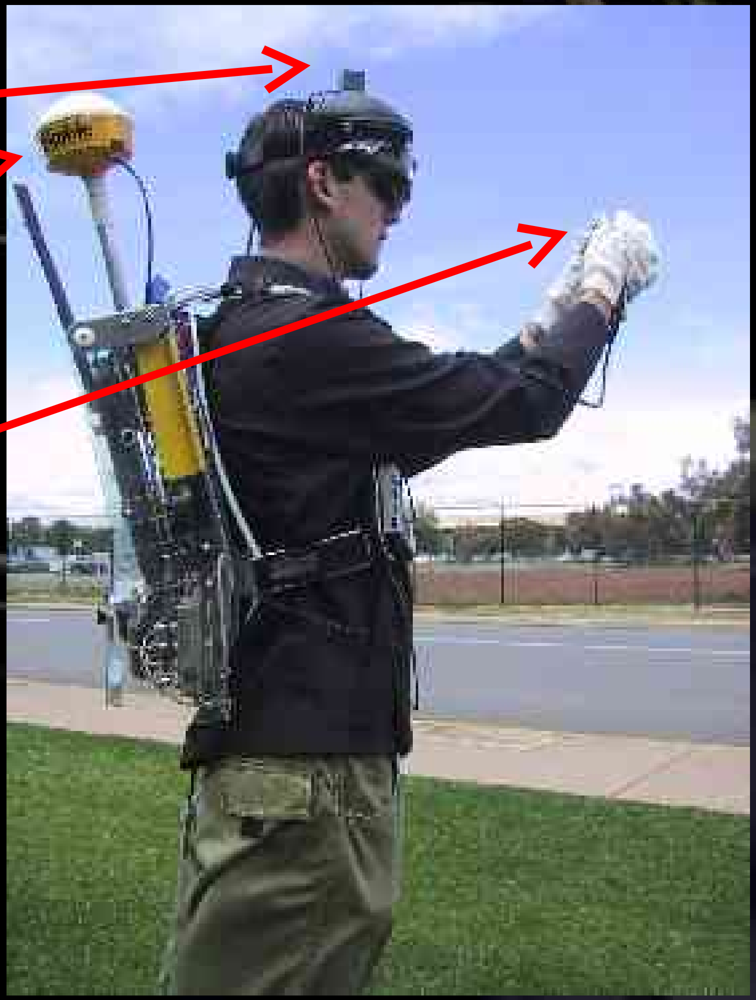


- Play demo video here

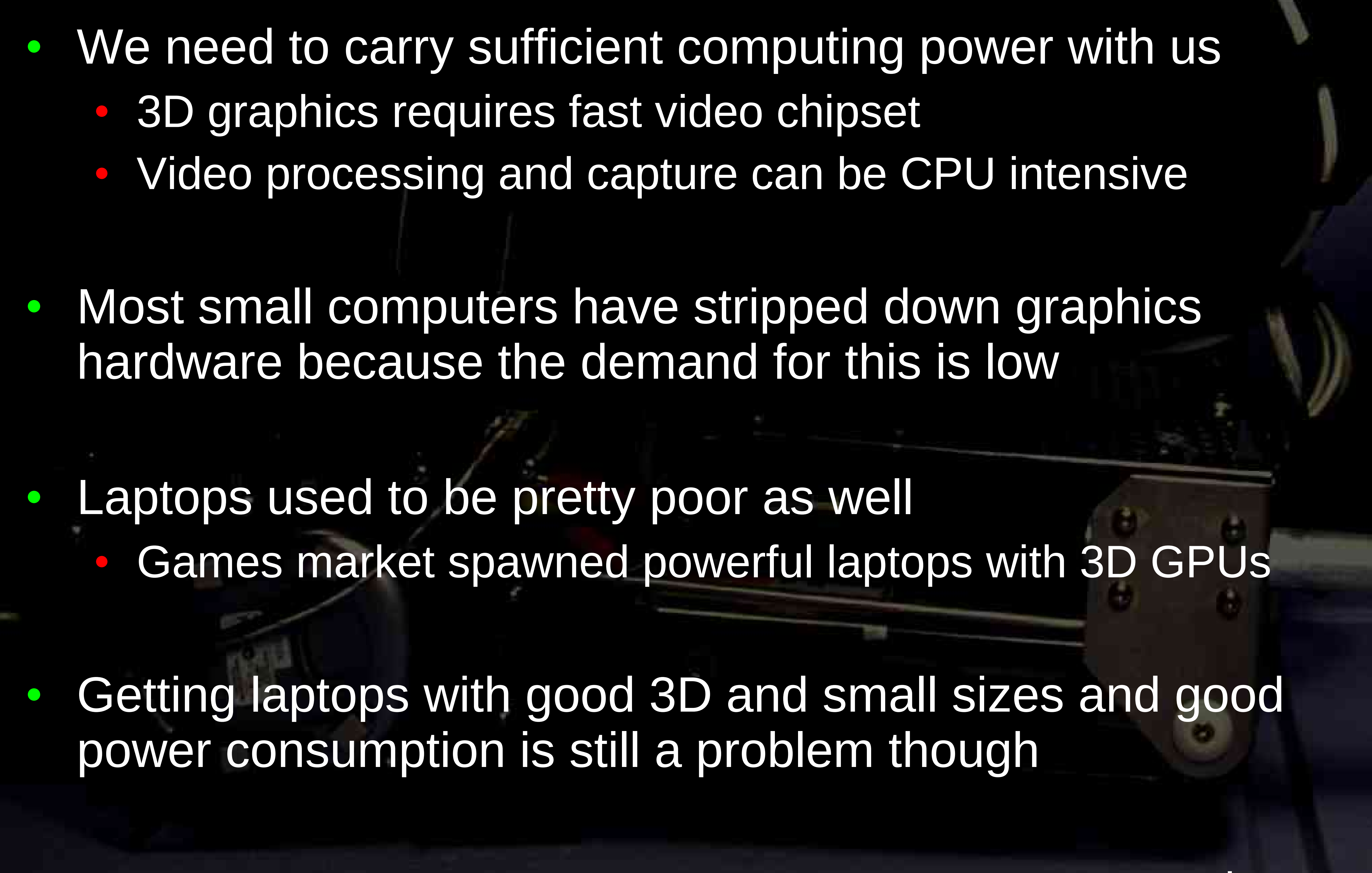
Tracking

- To generate a view, the computer needs to know the position and orientation of the user’s head
- May also require tracking of body parts and tools
- Restricts the types of user interfaces we can use!

- Accel/gyro/magnetic InertiaCube2
  - A$2500
- Trimble Ag132 GPS
  - A$6500
- ARToolKit vision tracking
  - Cost of video camera = $Cheap
- Magnetic, optical, ultrasonic, mechanical



Processing



- We need to carry sufficient computing power with us
  - 3D graphics requires fast video chipset
  - Video processing and capture can be CPU intensive
- Most small computers have stripped down graphics hardware because the demand for this is low
- Laptops used to be pretty poor as well
  - Games market spawned powerful laptops with 3D GPUs
- Getting laptops with good 3D and small sizes and good power consumption is still a problem though

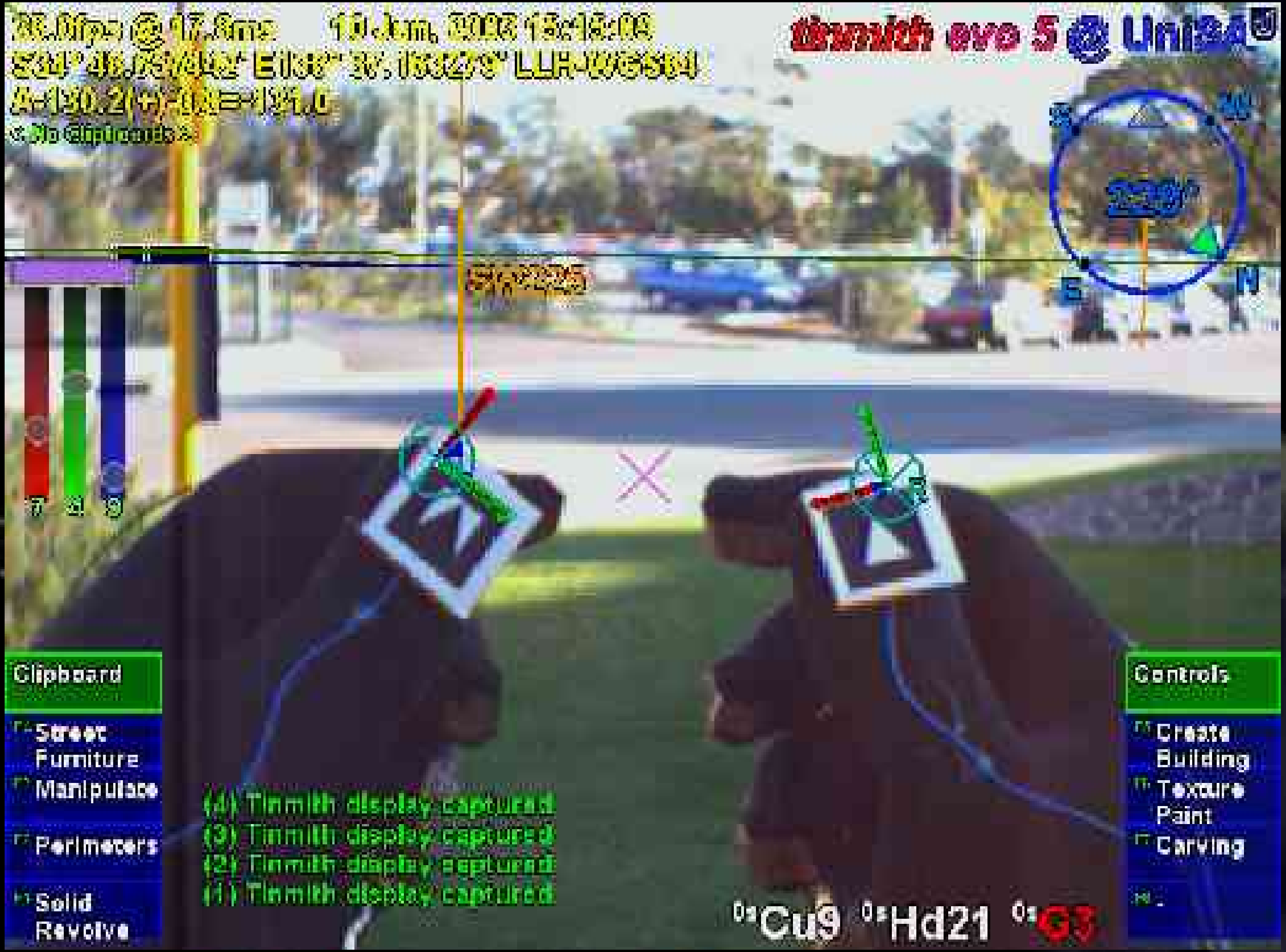
Indoor AR/VR

- Not everyone has a backpack like me

- Indoor setups for VR and AR
  - Still require expensive tracking hardware and HMD
  - Slightly easier because hardware can be bulky
  - Limited operating area

Free beer AR

- AR and VR are dominated by the cost of the hardware
- But free beer and free speech are also possible in AR!
- ARToolKit
  - Hirokazu Kato and Mark Billinghurst
  - University of Washington
- More on this later
- Show live demo



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Tutorial discussion

- Today we will talk about how to use
  - Video cameras
  - ARToolkit and OpenCV
  - 3D renderers
  - Custom hardware
- Goal is to allow creation of 3D apps to run on a desktop
  - What else is possible apart from the standard 2D UI?
- Lets get started!

Distribution installation

Distribution installation

- I currently use Debian as my platform of choice
  - Comes with lots of packages, some of which are obscure
  - You cannot use stable for this tutorial, it is way too old!
  - Testing and unstable keep breaking all the time, but it is fine if you are willing to fix up these problems
  - Debian also isn't all that friendly for obvious things

- Still looking for an ideal distribution
  - Knoppix breaks after a few months, Ubuntu looks promising with its 6 month stable cycles
  - I can’t afford to spend weeks configuring a machine
  - Simple things should be simple, complex to be possible

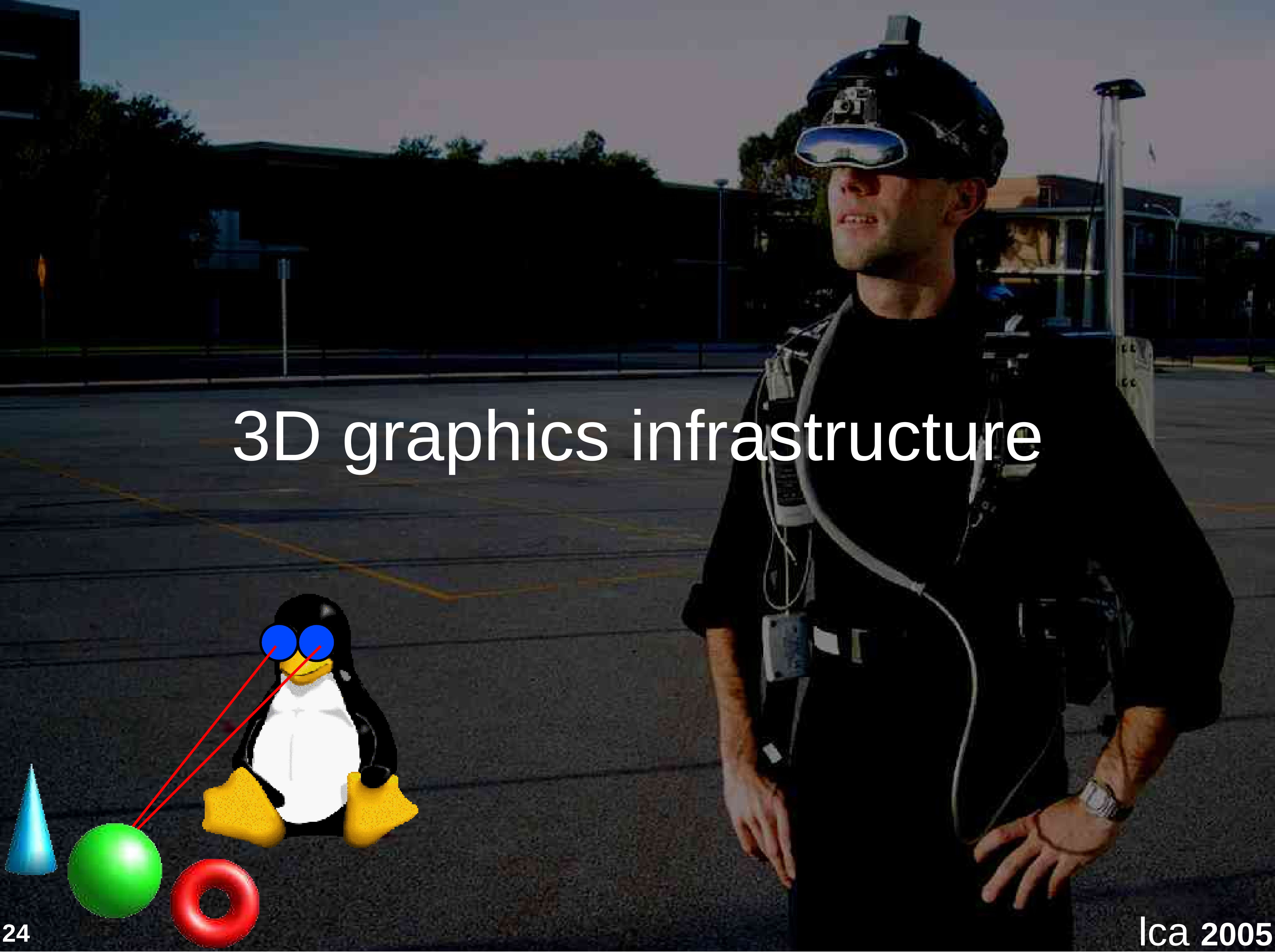
Software requirements

- Does not matter what distribution you use
  - To be on the safe side, install as much as you can so you can avoid chasing up missing packages

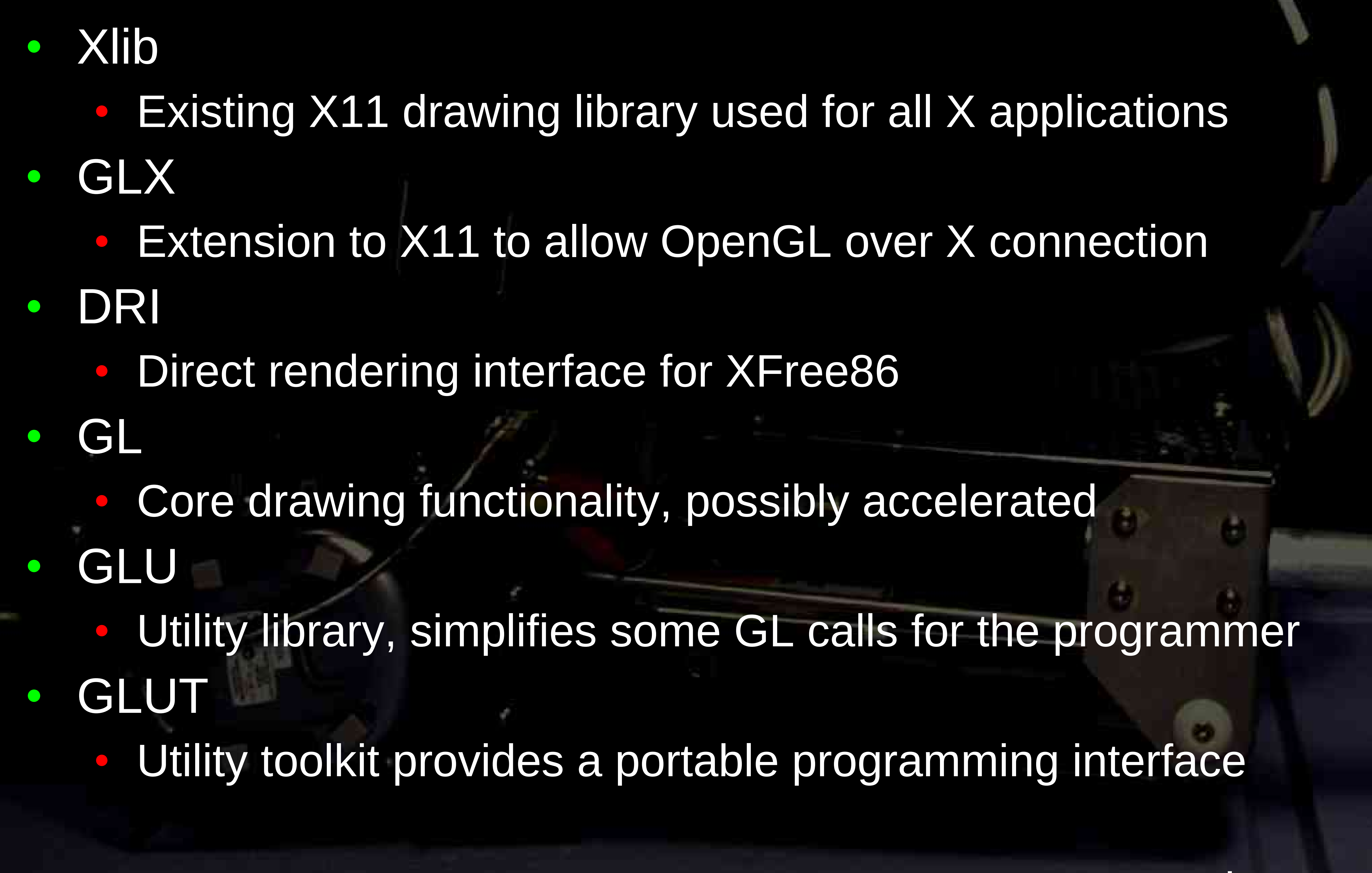
- Make sure you include (see notes)
  - Devel, XFree86, DRI, OpenGL, Kernel, Firewire

- I have prepared a set of Debian dependency packages
  - Add **http://www.tinmith.net/debian ./** to your sources.list
  - Install tinmith-devel and tinmith-desktop and this will add all the dependencies that you will need
  - I have gone to all the trouble to make installs easy for all

3D graphics infrastructure



Graphics libraries



- Xlib
  - Existing X11 drawing library used for all X applications
- GLX
  - Extension to X11 to allow OpenGL over X connection
- DRI
  - Direct rendering interface for XFree86
- GL
  - Core drawing functionality, possibly accelerated
- GLU
  - Utility library, simplifies some GL calls for the programmer
- GLUT
  - Utility toolkit provides a portable programming interface

OpenGL advantages

- Previously, required both X server and client processes
- For intensive drawing you waste a lot of CPU time
  - X protocol and memory usage
  - Kernel read() and write() calls
  - Task switching
  - X is not very good at massive primitive numbers
- This is why SGI implemented direct rendering
- Now we have GLX and DRI in XFree86 based on this

- Server sets up video card for security
- Client can then run without any intervention
- System calls are evil, we can avoid them now!

3D hardware is cheap

- Nowadays 3D hardware is available in almost all PCs
- Old cards are still excellent, get them for free from people throwing them away!
- Older cards have more mature drivers as well

- 3D drivers are very complicated monsters!

- Most cards do not use hardware for all OpenGL calls, only the most commonly used calls
- SGI used to implement full hardware support though

Nvidia and ATI

- Nvidia provide well supported closed source binaries
  - TNT2 is reasonable, GeForce2 is minimum recommended
  - Used this extensively on many boxes with good results
  - Same code base as Windows so has good performance
  - Excellent reliability (watch out for some 2.6.x kernels)

- DRI provide open source driver for ATI cards up to 9200
  - Works ok but still has lots of bugs in it on my 9000 laptop
  - DRI does not support any cards past Radeon 9200
  - ATI provide binary drivers but they are not well supported

- I will chose Nvidia any day, Radeons are not as good

Nvidia and ATI

- Avoid other hardware if you can
  - Integrated chipsets are much slower
  - Nvidia and ATI are the two big players
  - Drivers tend to be not as good for less mainstream gear
  - Only people with laptops should not be using ATI/Nvidia

- Nvidia versus ATI always starts religious flame wars
  - Nvidia do not release specifications for their cards, but they do provide good quality drivers that work
  - I need to use hardware that works and is reliable, there is no point using software that causes trouble if it can be avoided

Learning OpenGL

- OpenGL Red Book is what everyone learns from
  - Available online for free as a PDF, also lots of tutorials

- OpenGL is beautifully designed and super easy to learn
  - It is not convoluted and tricky like Xlib
  - Simple things are simple
  - Optimisation and tricky things are still possible

- Supports primitive rendering, shading, textures, depth buffering, 2D and 3D projections, linear transformations, and display lists
  - Everything you need to write both 2D and 3D applications
  - X supports 2D primitives and windowing, that’s about it

Using OpenGL

- I write most of my apps using pure OpenGL now
- I use X only as a way of opening a window for OpenGL

- No way under X to draw lots of primitives without incurring the overheads described before
  - If you use X then you get hardware acceleration but you are limited by client/server overheads
  - If you draw locally you can use SHM and DGA to copy direct to hardware but you have no primitive acceleration

- I've always wanted an Xlib which was compiled directly into the client or allowed direct access to the hardware
  - We now have it in the form of DRI

Catches of OpenGL

- Pipelined in video card to maximise performance
  - May introduce some latency, not sure how much
  - Doesn’t seem to cause a problem for live video though
- OpenGL is just a renderer, whereas X has toolkits on top of it like Qt and GTK
  - Some toolkits have been ported to OpenGL recently though

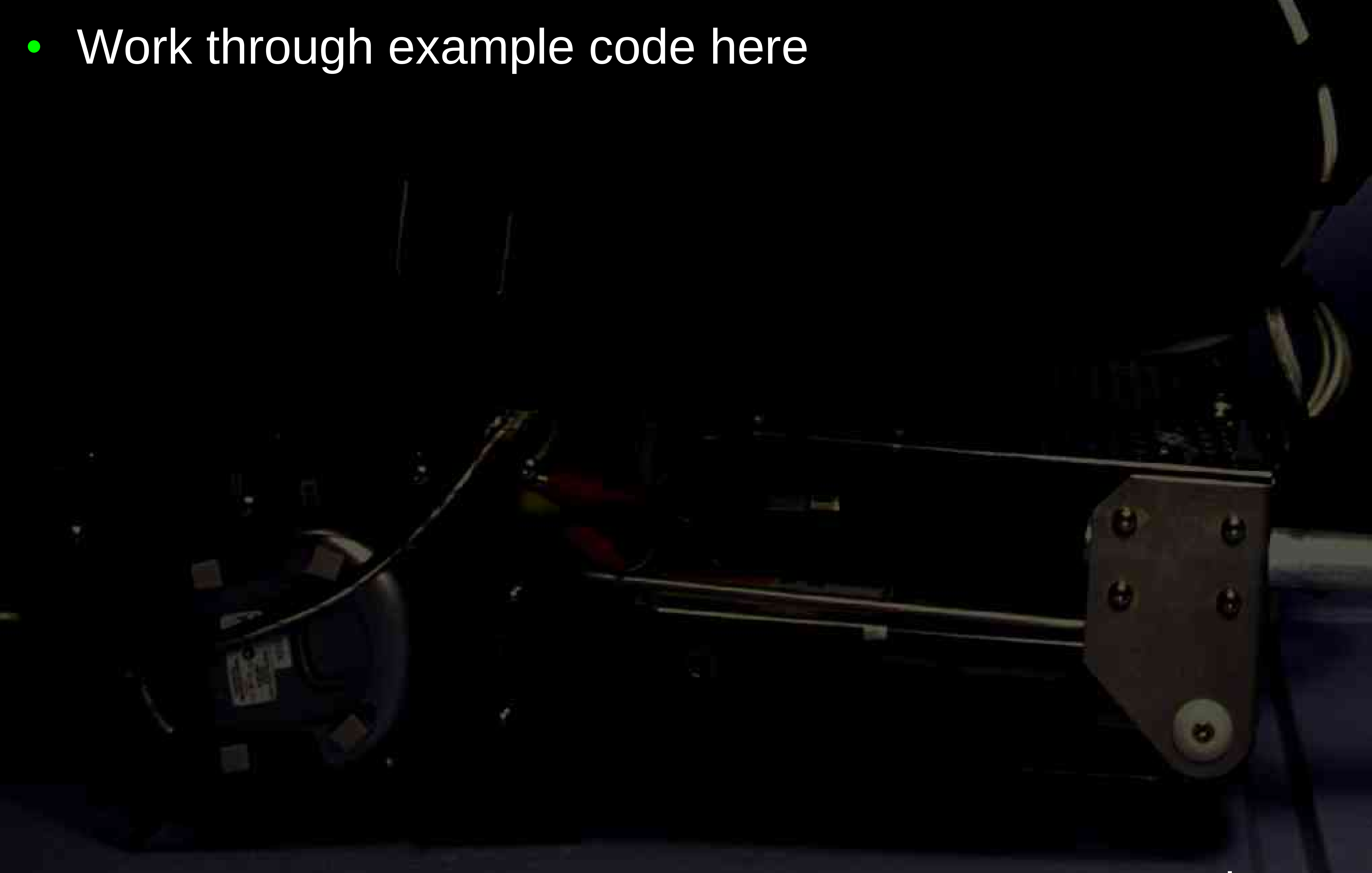
Useful example

- X has trouble displaying live video
  - MIT SHM, Xvideo, DGA, etc
  - Each driver in XFree86 supports some but not others
  - You have to write your client to support all of them!
  - X doesn’t expose the entire acceleration of the video card

- OpenGL can display texture maps natively
  - Not just render but perform warping, scaling, etc
  - Can render to flat 2D or any 3D polygon!
  - OpenGL is written to assume acceleration, so it will take advantage of as much as is available
  - Supports auto format conversions (RGB, YUV, B&W)
    - » Show application demo here

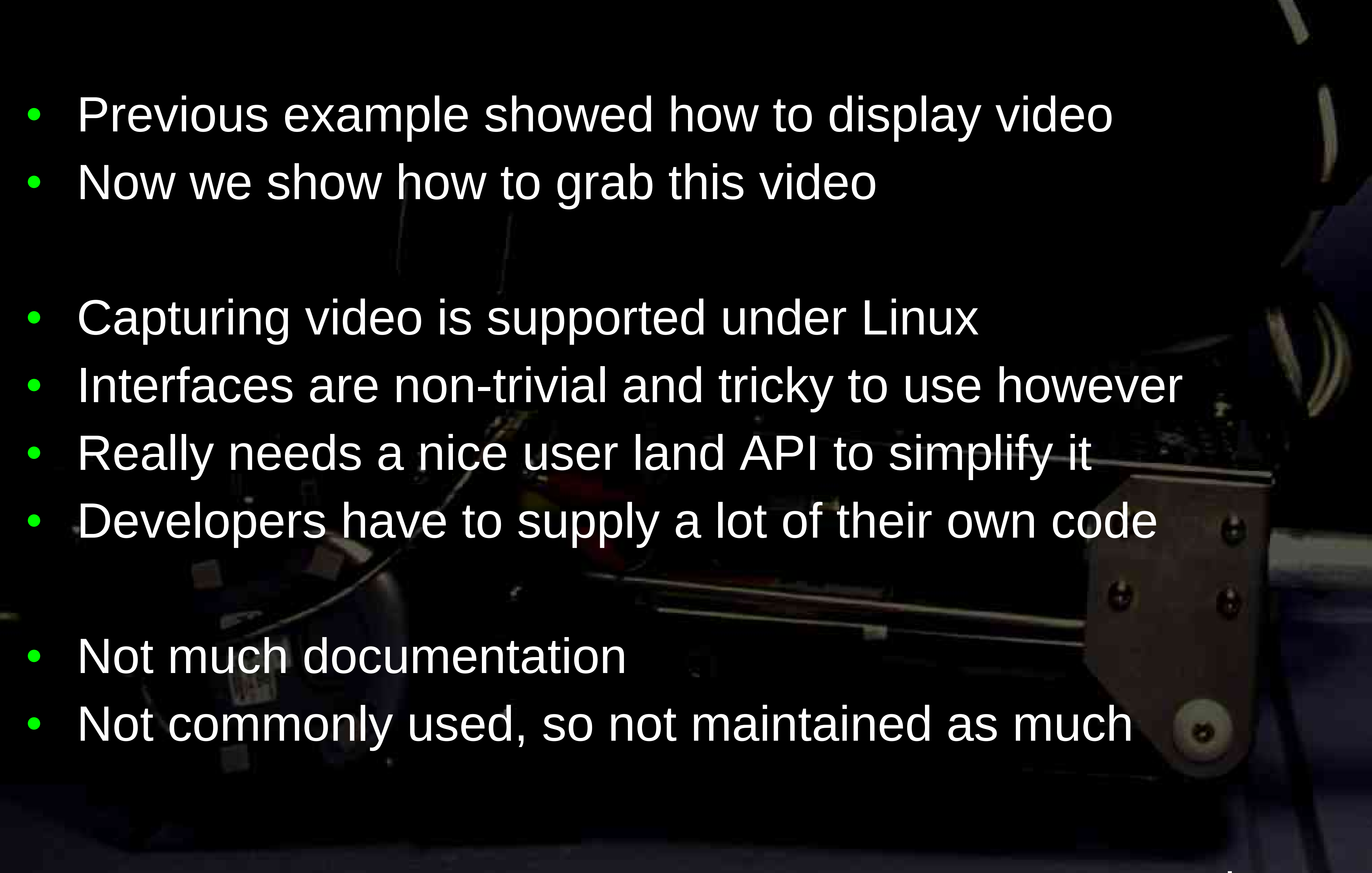
Video display source code

- Work through example code here



Live video capture

Capturing video



- Previous example showed how to display video
- Now we show how to grab this video

- Capturing video is supported under Linux
- Interfaces are non-trivial and tricky to use however
- Really needs a nice user land API to simplify it
- Developers have to supply a lot of their own code

- Not much documentation
- Not commonly used, so not maintained as much

Video 4 Linux

- V4L was the first common kernel API for capture drivers
  - PCI capture boards, USB cameras
  - Xawtv display program

- Simple interface calls
  - open() – initialise device
  - read() – read data from camera, can also use mmap()
  - ioctl() – configure capture settings

- You can specify resolution and pixel format (RGB, YUV) but the device must support it
- If not then you must supply your own conversion

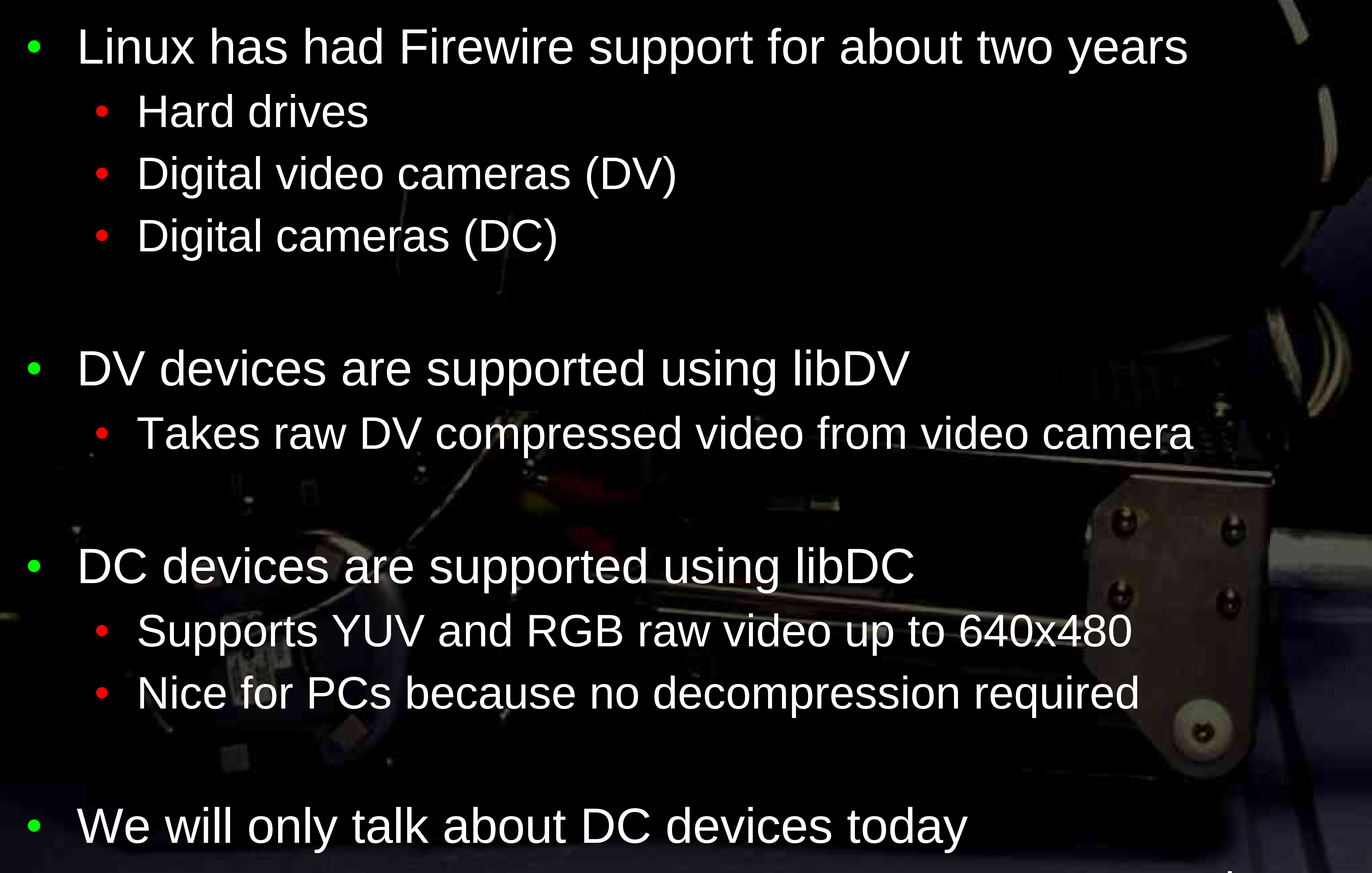
Video 4 Linux

- If you have trouble using V4L, reload the modules
- I found the CPIA camera driver was not very reliable and my camera doesn't work in 2.6 at all any more
- USB2.0 cameras are not supported

- New V4L2 API is available in kernel 2.5 and 2.6
  - Not all drivers use this new API
  - Older V4L apps are supported via compatibility layer
  - Designed to fix some flaws in old V4L
  - Still needs a nice user land interface library

- Go through example V4L code

Firewire video capture



- Linux has had Firewire support for about two years
  - Hard drives
  - Digital video cameras (DV)
  - Digital cameras (DC)
- DV devices are supported using libDV
  - Takes raw DV compressed video from video camera
- DC devices are supported using libDC
  - Supports YUV and RGB raw video up to 640x480
  - Nice for PCs because no decompression required
- We will only talk about DC devices today

libDC video capture

- The libDC library is complicated and has almost no documentation except for some include files
  - There are many versions, use -11/v1.0 release for stability!
- The easiest way to capture from DC devices is to use the ARToolKit or OpenCV interfaces
  - LibDC is not well documented, so it is easier to use someone elses interface
- The DC specification defines interface for all cameras
  - Very nice because ALL 1394 cameras work with Linux!
  - Contrast to USB cameras where there is no standard and very poor driver support
  - I have bet the farm on DC cameras, they are a bit more expensive but they are nice to use

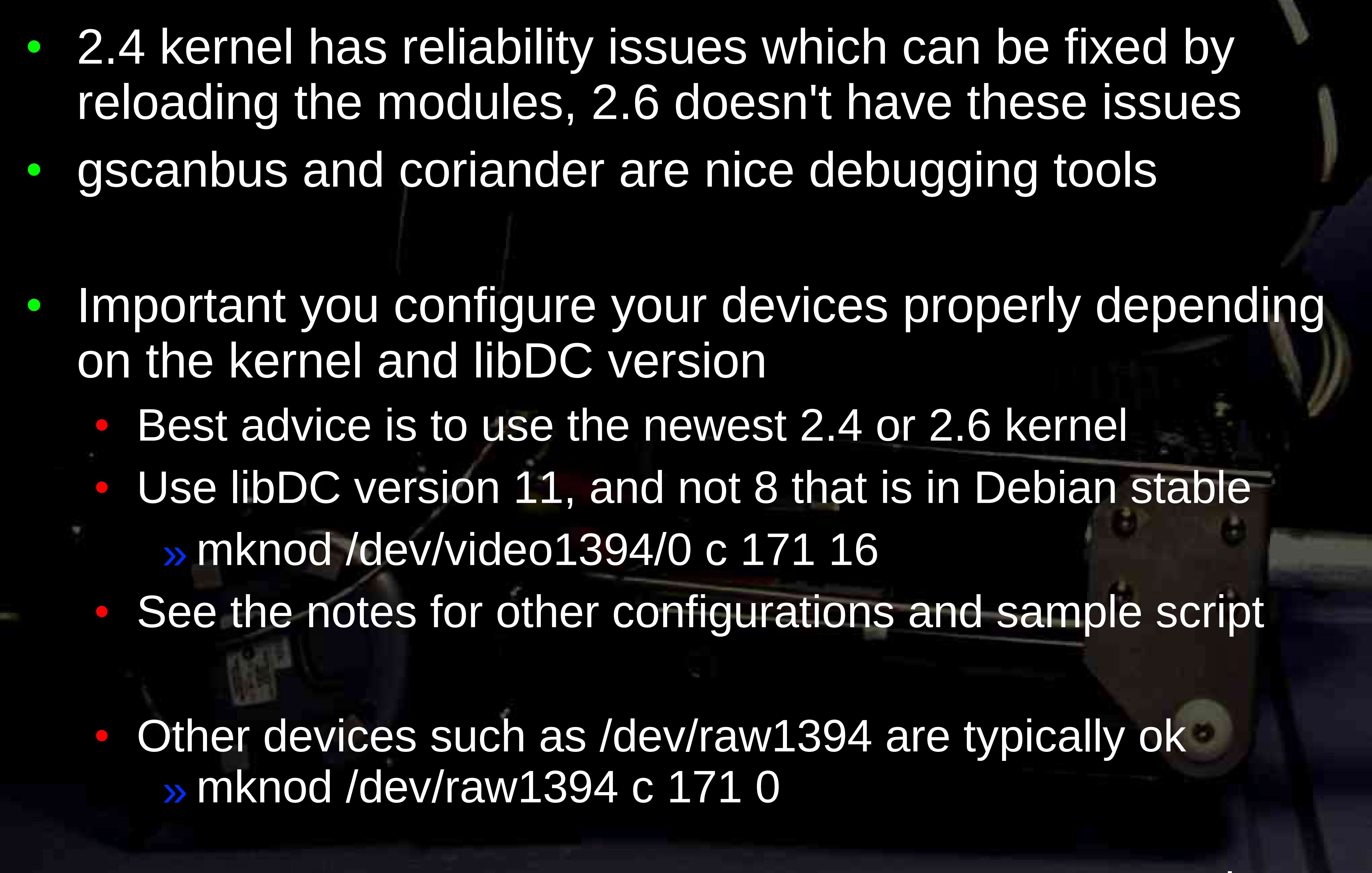
Using DC devices

- The RGB24 mode is nice because you can take the raw image data and work with it straight away
  - Wastes bandwidth but CPU is not used much
  - USB cameras tend to operate using some compression

- Coriander is a nice program for playing with cameras
  - All devices have controllable settings which is nice
- Gscanbus is a nice tool for listing out 1394 devices

- I found that DC devices are much more robust and reliable than the CPIA USB camera I used before
  - I have used the Pyro Webcam and Point Gray Firefly

Tricks to using DC devices



- 2.4 kernel has reliability issues which can be fixed by reloading the modules, 2.6 doesn't have these issues
- gscanbus and coriander are nice debugging tools

- Important you configure your devices properly depending on the kernel and libDC version
  - Best advice is to use the newest 2.4 or 2.6 kernel
  - Use libDC version 11, and not 8 that is in Debian stable
    - » mknod /dev/video1394/0 c 171 16
  - See the notes for other configurations and sample script

  - Other devices such as /dev/raw1394 are typically ok
    - » mknod /dev/raw1394 c 171 0

Vision tracking

Intro to vision tracking

- We can use video cameras to capture the physical world
- Computers can analyse the images to extract information

- There has been a lot of talk about vision tracking coming soon but not really much action

- The ARToolKit is a nice example of a library we can use now to begin developing apps, without much knowledge

- I will show how ARToolKit works and some examples

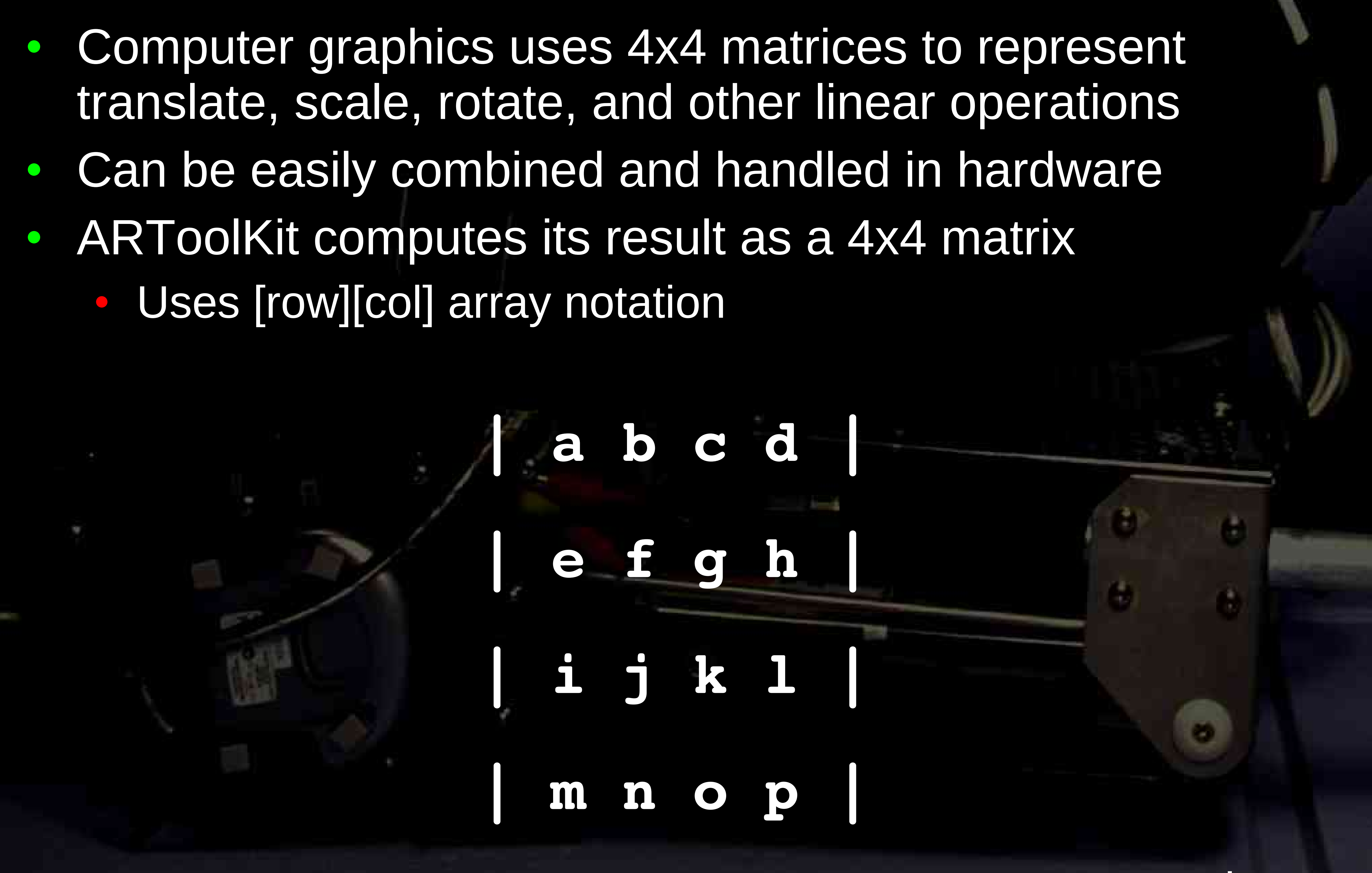
ARToolKit processing

- Capture video frame
- Extract out edges
- Calculate rotation and translation
- Match against pattern database
- Profit!
  - well ... just a matrix :)

- Walk through simpleTest

Pulling apart 4x4 matrices

- Computer graphics uses 4x4 matrices to represent translate, scale, rotate, and other linear operations
- Can be easily combined and handled in hardware
- ARToolKit computes its result as a 4x4 matrix
  - Uses [row][col] array notation



$$\begin{vmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ m & n & o & p \end{vmatrix}$$

Example matrix operations

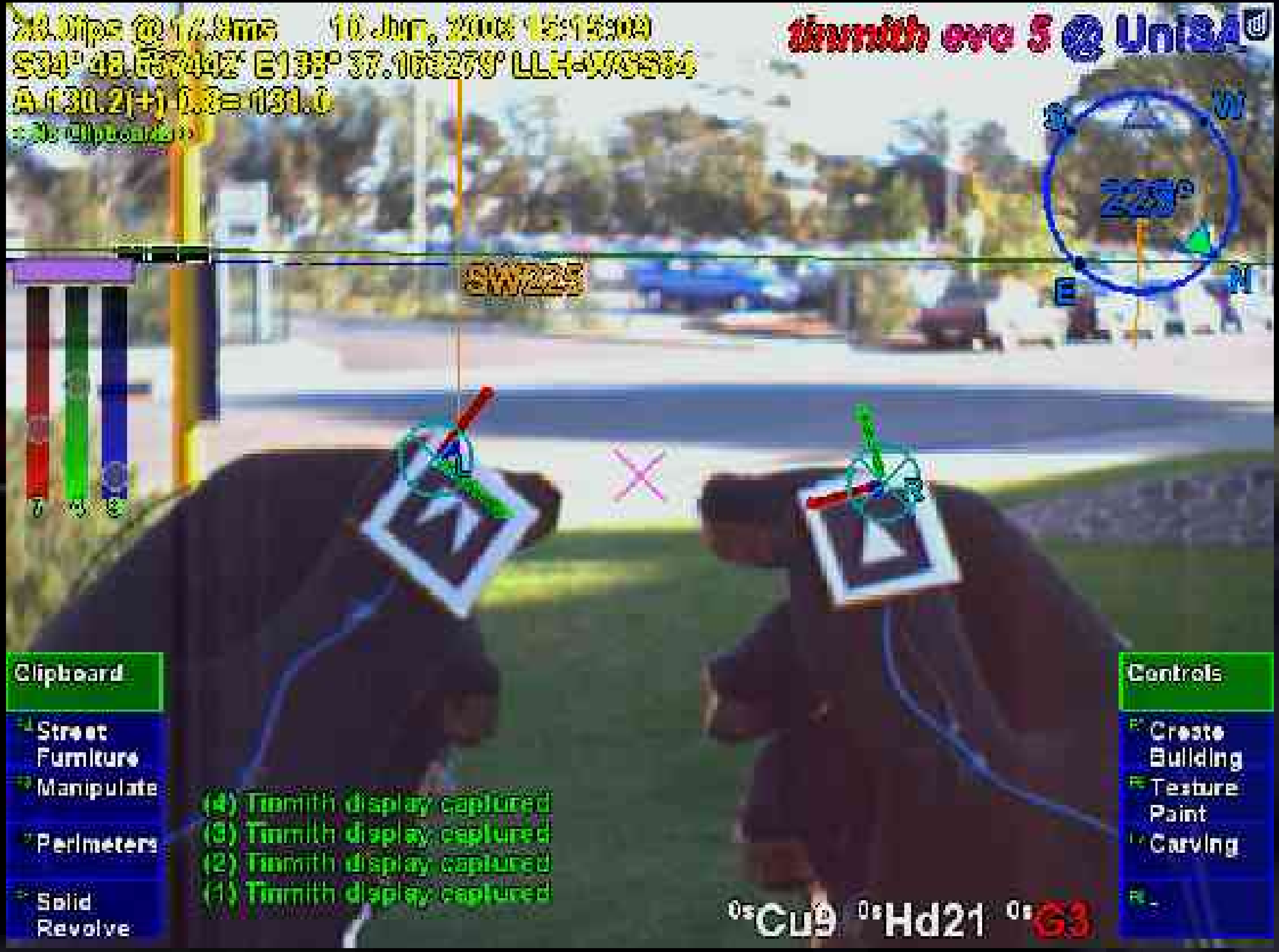
- Identity Trans Scale

```
| 1 0 0 0 |      | 1 0 0 Tx |      | Sx 0  0  0 |
| 0 1 0 0 |      | 0 1 0 Ty |      | 0  Sy 0  0 |
| 0 0 1 0 |      | 0 0 1 Tz |      | 0  0  Sz 0 |
| 0 0 0 1 |      | 0 0 0 1  |      | 0  0  0  1 |
```

- To extract out translation, grab
  - X = matrix [0][3]
  - Y = matrix [1][3]
  - Z = matrix [2][3]
- Rotation and scale are beyond the scope of this tutorial!
  - See a good graphics text book for info on how these work

Using ARToolKit as a tracker

- I use ARToolKit as a tracker for my hands
  - Markers placed on each thumb
  - Extract out XYZ coordinates from the matrix
  - Project 3D coordinates to display to get 2D
- Use it to track your hands in front of your monitor?
  Attach a camera to a baseball cap that you wear?
- Generate real mouse events for X11?
- Control Gnome/KDE?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A 130.2(+) 0.8= 131.0
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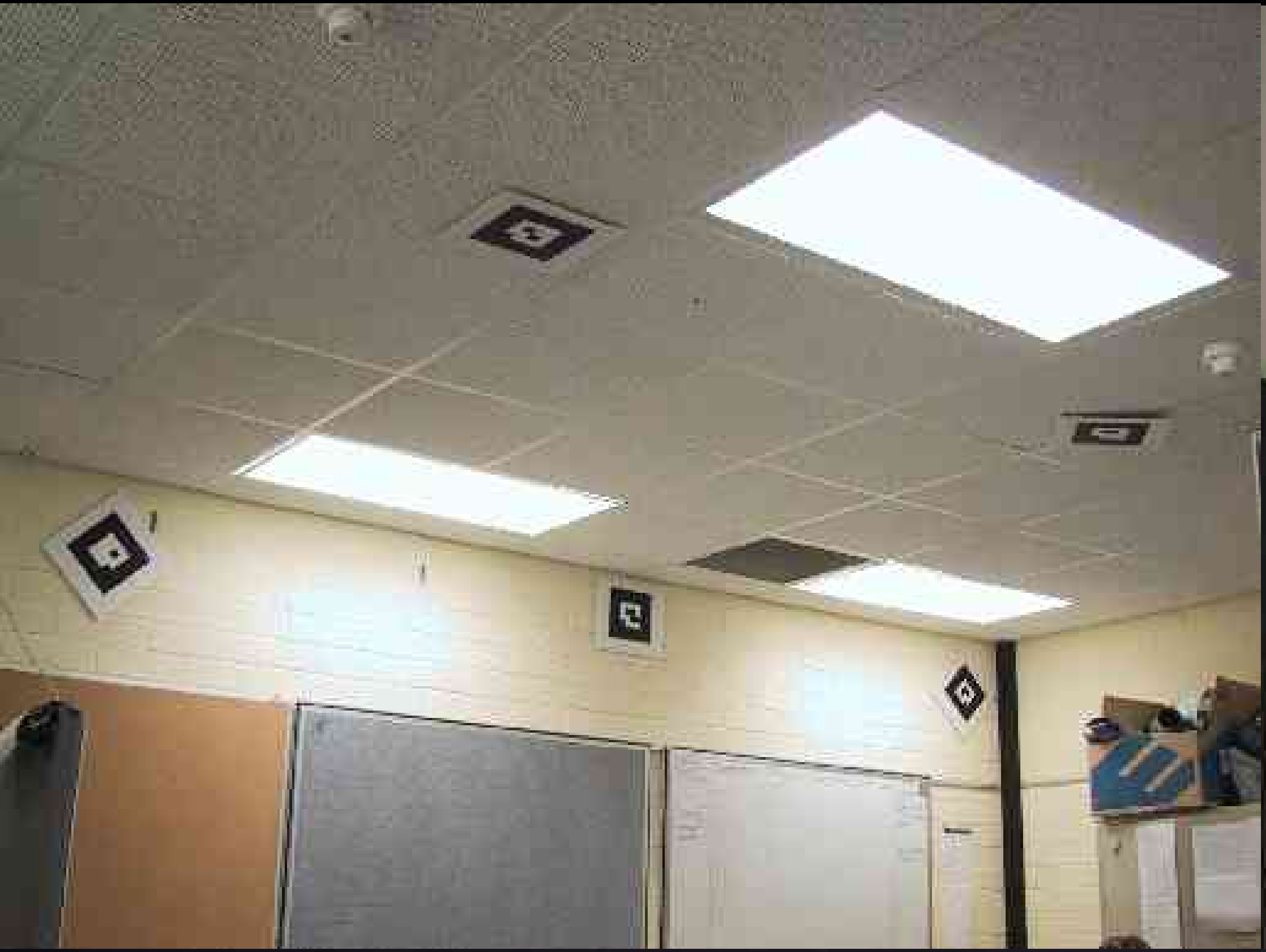
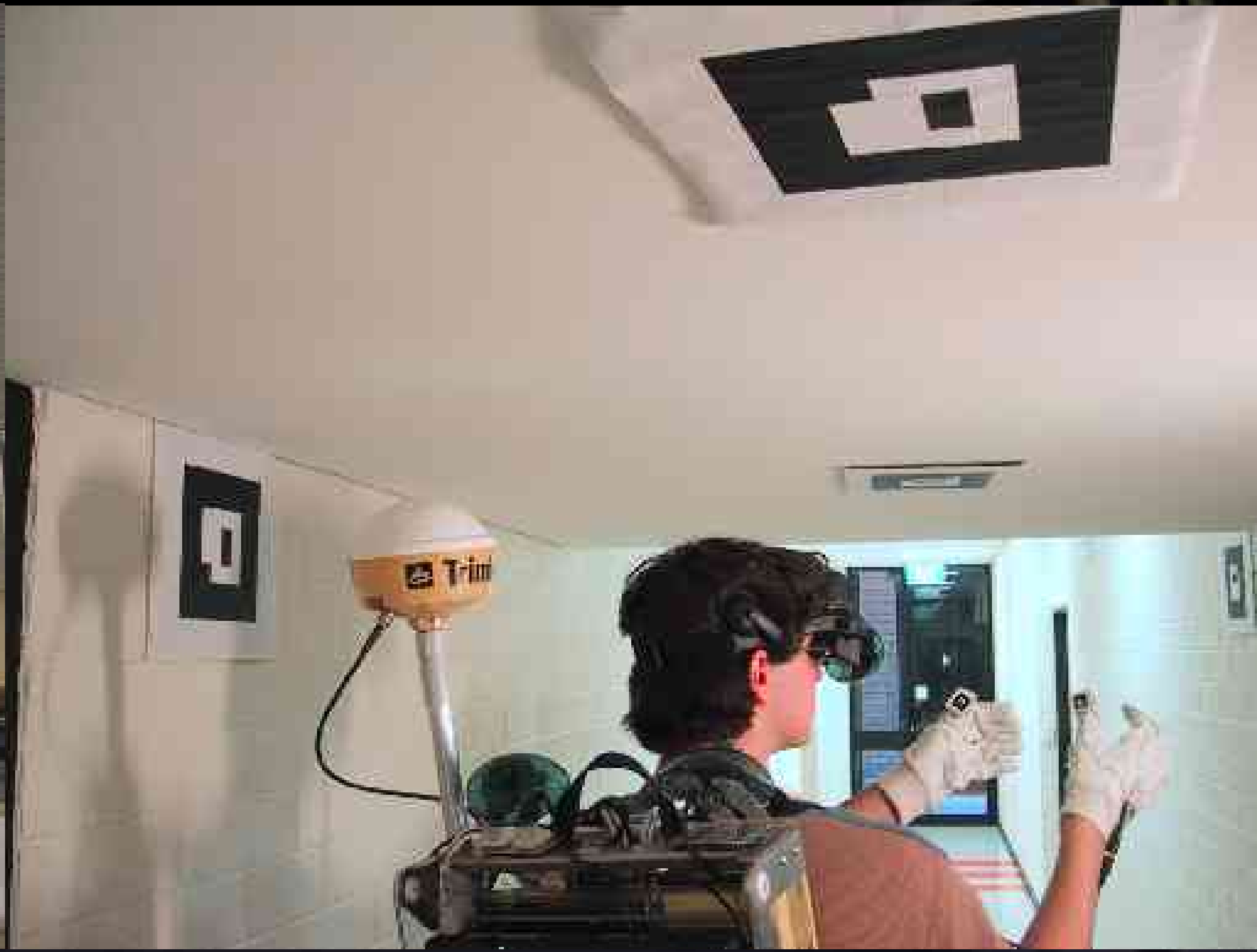
Tracking position in a room

- Multiple cameras observe markers on the ceiling
- Inverse the matrix to find camera relative to the marker
- Must measure each marker relative to the room
- This one is a lot harder than it looks!





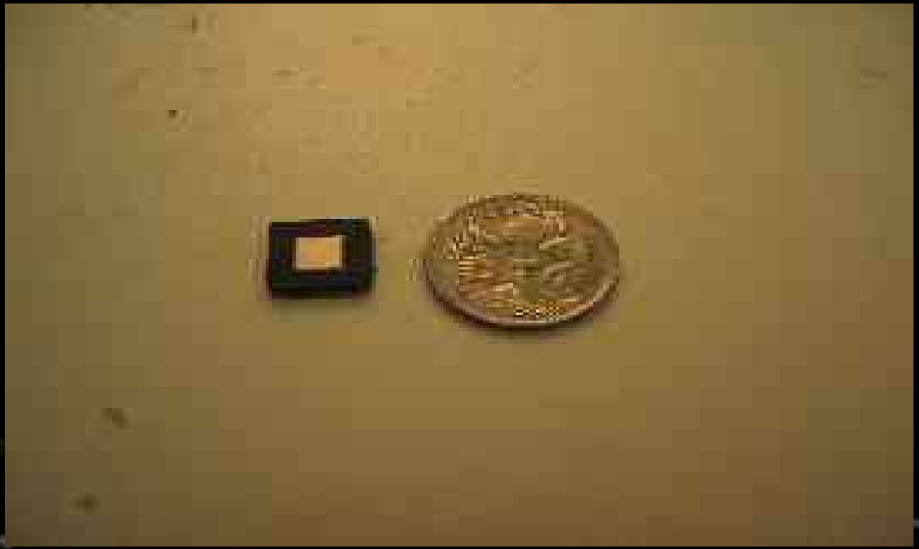
Custom hardware

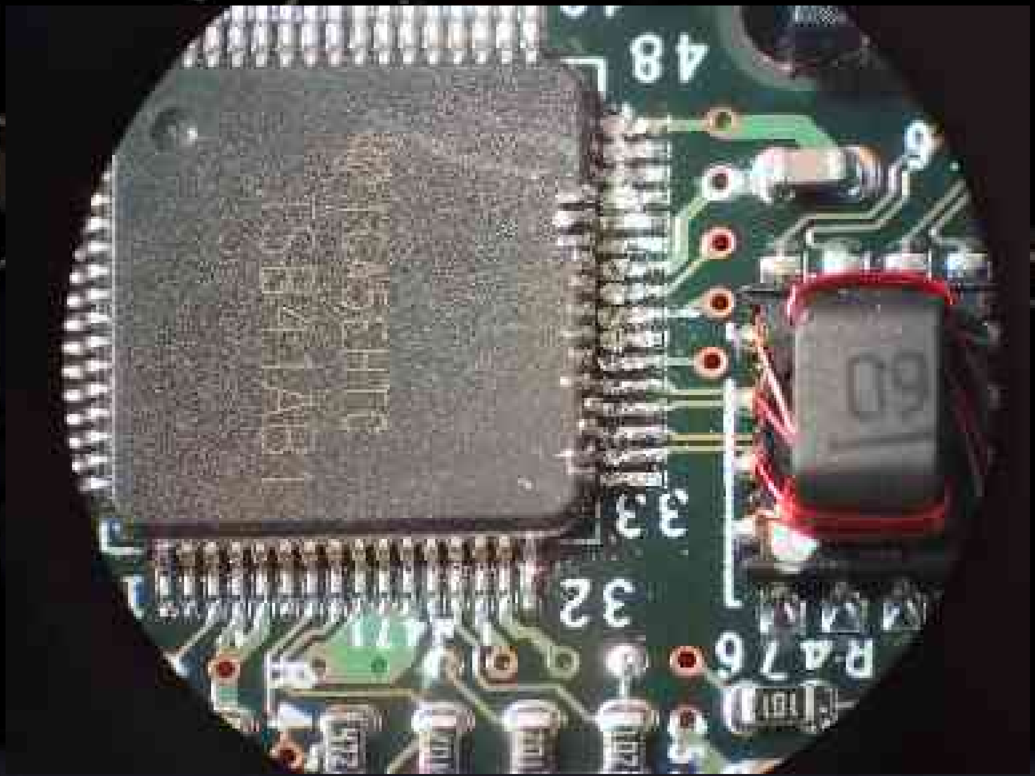
Important note

- Hacking is not just about software!
- It is about using tools to modify your hardware and also make new cool devices
  - Drills
  - Power Saws
  - Soldering Irons
  - Sticky Tape
  - Plastic and Metal
- And you make lots of mistakes along the way
- Combine the two for even more fun!

WCL Project Oxcart

- Repair damaged 1394 controller chip in Dell 8100 laptop
  - Texas Instruments TSB41AB1, 64-pin surface mount IC
  - 8 hour surgery
  - Saved $1200
  - Cost $5 plus time
  - Fun!



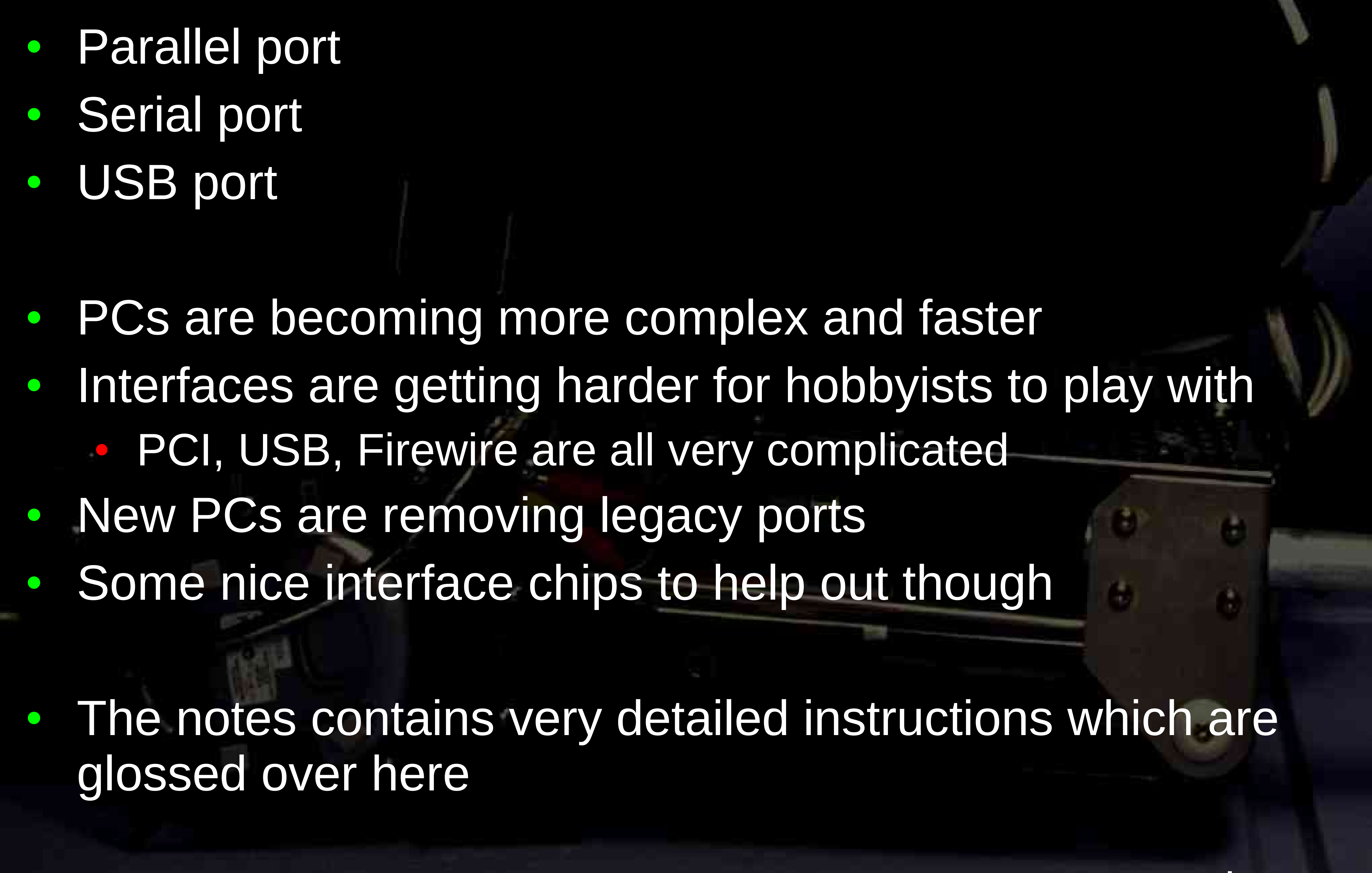


Interfacing technology

- Parallel port
- Serial port
- USB port

- PCs are becoming more complex and faster
- Interfaces are getting harder for hobbyists to play with
  - PCI, USB, Firewire are all very complicated
- New PCs are removing legacy ports
- Some nice interface chips to help out though

- The notes contains very detailed instructions which are glossed over here



Parallel port

- 25-pin D shell connector
- 8 data lines capable of +5V with low current
- Old ports are only single direction
- Other flow control lines also capable of data transfer
- Write directly to address using ioperm() and outb()
- LED CPU Meter provided in the example archive

- CPU must bang out each byte manually
- Interrupt for each incoming byte or intensive polling

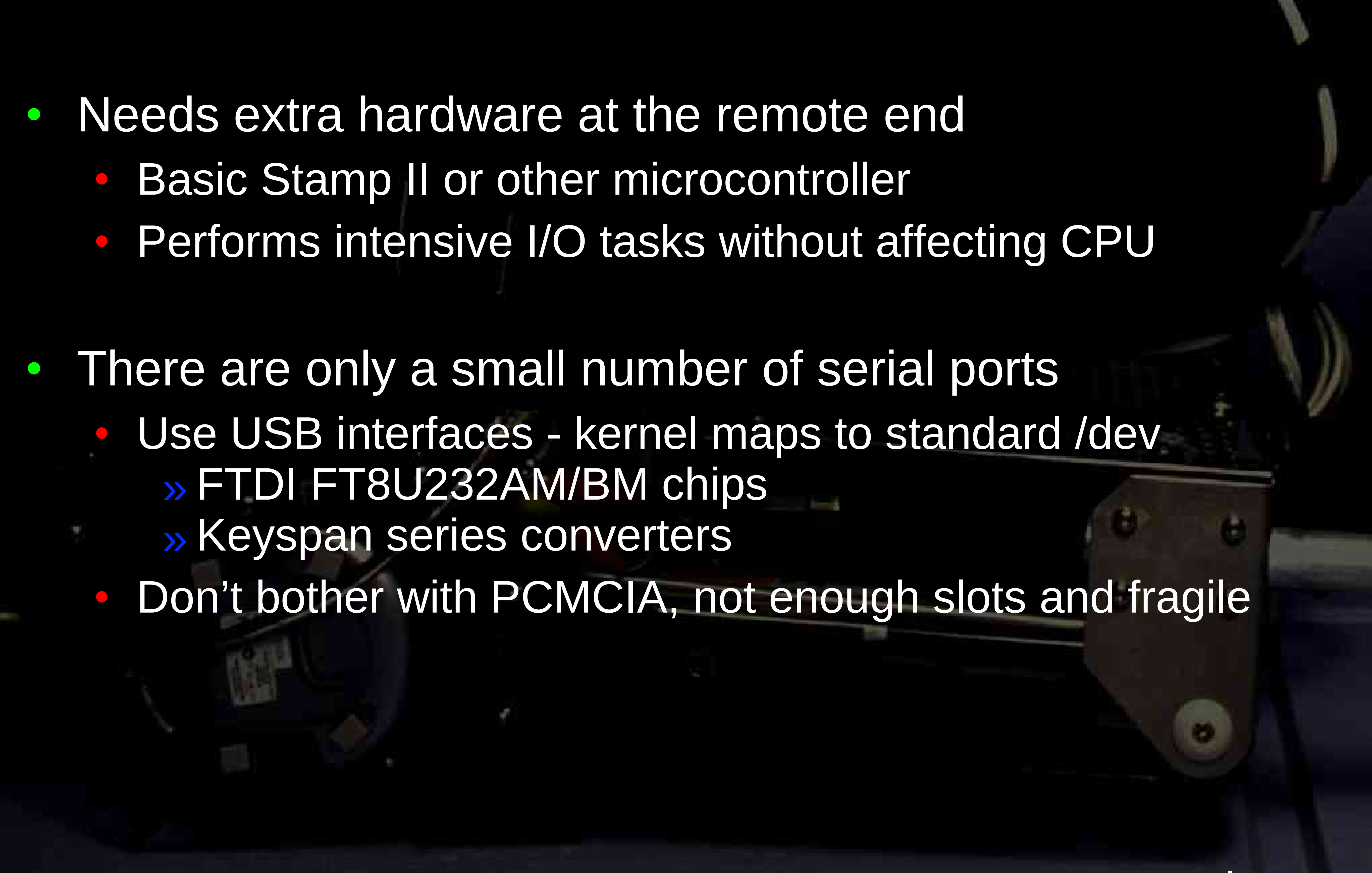
- Linux isn’t really designed for any of these
- DOS is actually ideal for using these

Serial RS-232

- 9-pin D shell connector

- Baud rates up to 115,200 bps (slower than parallel)
- Much more friendly on the CPU with large UART buffers
- Simple cables with only 3 wires needed
- Requires a port for each device, limited on laptops
- Open up device and use standard I/O calls on an FD
  - This can be quite tricky to get right
  - I have supplied some example code for RS-232

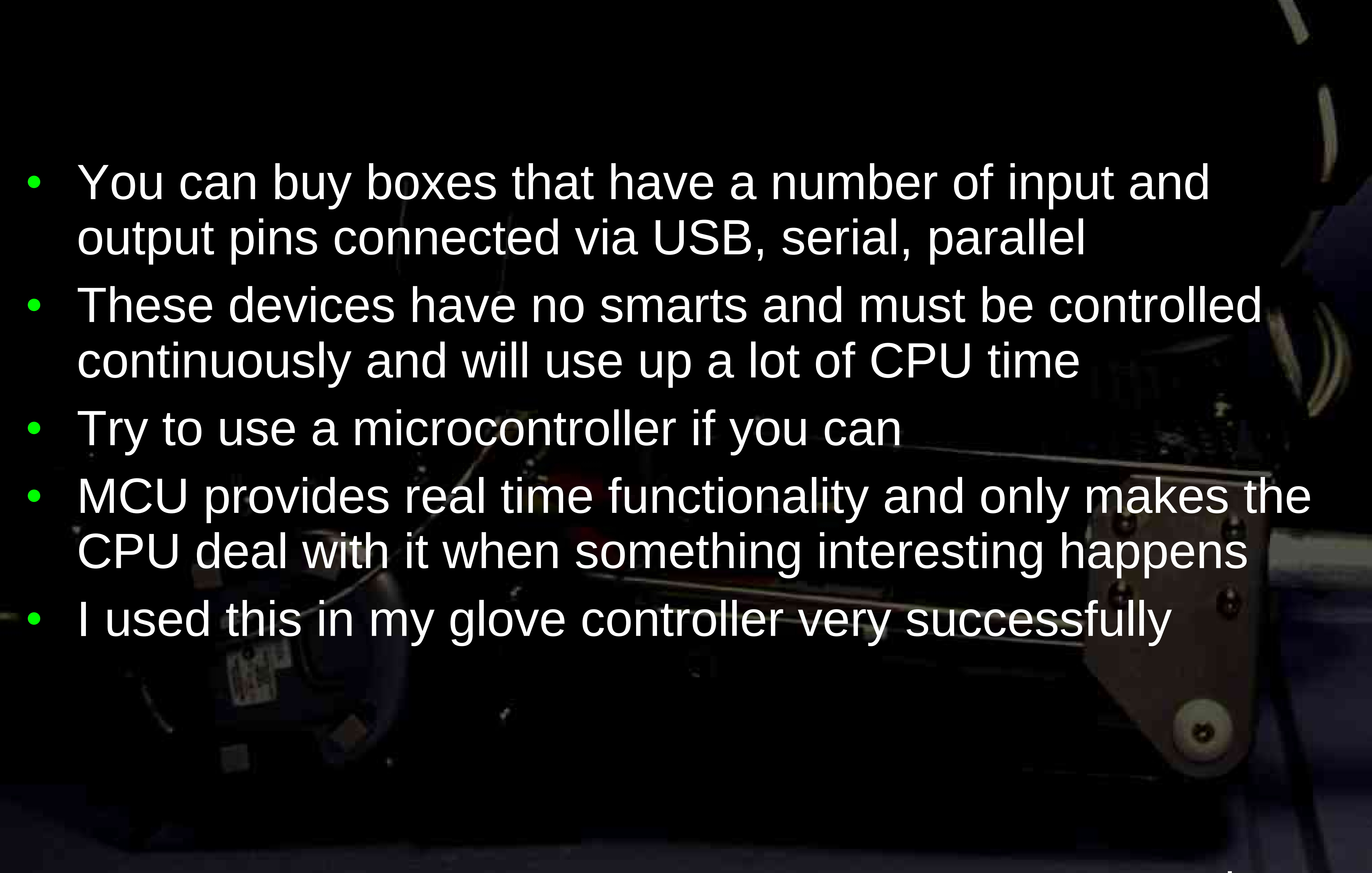
Serial RS-232



- Needs extra hardware at the remote end
  - Basic Stamp II or other microcontroller
  - Performs intensive I/O tasks without affecting CPU

- There are only a small number of serial ports
  - Use USB interfaces - kernel maps to standard /dev
    - » FTDI FT8U232AM/BM chips
    - » Keyspan series converters
  - Don’t bother with PCMCIA, not enough slots and fragile

Dumb controller boxes



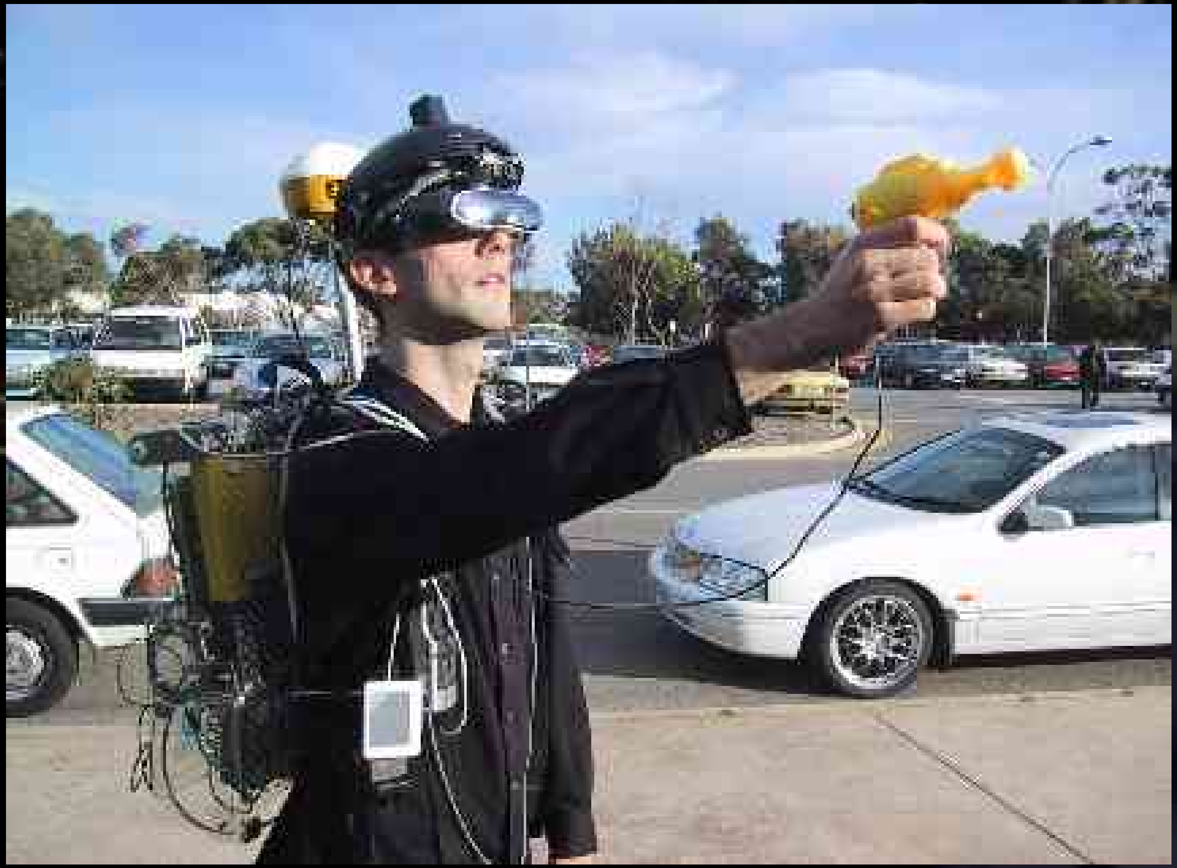
- You can buy boxes that have a number of input and output pins connected via USB, serial, parallel
- These devices have no smarts and must be controlled continuously and will use up a lot of CPU time
- Try to use a microcontroller if you can
- MCU provides real time functionality and only makes the CPU deal with it when something interesting happens
- I used this in my glove controller very successfully

Cheap hacks

- USB mice have three or more buttons
- Interfaces are already built
- Simply cut open and solder custom switches
- Applications that use a mouse need no modifications
- Use an old mouse or get a cheap one

- Why work when you don’t have to?

- Hacking existing gear is much easier and saves time and money



Conclusion

Conclusion

- We have talked about a lot of material today
- We had to gloss over a lot because of time restrictions
  - The notes contain lots of detail about everything I have talked about today
  - Available from http://www.tinmith.net/lca2005

- Talked about video capture and display, 3D vision tracking libraries, and building custom hardware

- I look forward to seeing what people have built by the next Linux Conf!

Questions?

- Good luck, and don't fry your hardware!

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