OPEN GAMES CONSOLE

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ABSTRACT

This document presents the results of an experiment to determine whether it is plausible to design & build an open games console. Such an inquiry is interesting for numerous reasons - chief amongst them the potential for an open console platform to provide serious competition to commercial game consoles.

This document begins with a summary of games technology to date, which was further detailed in the literature review performed as a precursor to this thesis.

It then moves on to document the process by which the author designed a prototype console, as the practical aspect of this thesis. The design section includes a summary of options available, and a discussion of those options, leading to a conclusion as to which are the most appropriate.

The Assembly section looks at how the prototype Open Games Console was constructed. It looks in particular at the practical issues encountered, and suggests solutions or paths for future investigation.

In conclusion, it is found that an open games console is not yet a reality, but the technology and economy required to build one may be just around the corner. In particular, the experiment was not a total failure and did yield some positive results, including a working system with potential in areas beyond just console gaming, including as a multimedia hub, home appliance, or cheap multipurpose PC.

ACKNOWLEDGEMENTS

First and foremost to be thanked is Dr. John Rankin for supervising the thesis, enduring it's slow development and providing inspiration for the experiment.

Also essential to this thesis were Robert Ross and Shane Sweeney, both of whom contributed parts and equipment in aid of the construction of a prototype of the Open Games Console.

Thanks are also warranted for the La Trobe Computer Science department for authorising the thesis and committing to it's research, development and evaluation.

On a personal note, a heartfelt thanks to all those who endured the author's grumpiness, sourness and tiredness during the thesis. These include people at home - friends and family - as well as school peers, lecturers and others too numerous to mention. May you never be burdened with this again.

Finally, thanks also to the researchers, journalists and hackers who came before, who walked the road less travelled, and carved a path that might be followed by those such as the author. Without their motivation to disseminate knowledge to others, the experiment would not have been nearly as successful, and may indeed never have been conceived at all.

This is, in fact, a special thanks to the human spirit that endeavours to learn and to teach, without which our very lives would not be possible.

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1.0 Introduction

For all their astronomical success, there is a real problem with modern consoles - they are not open. They are produced by commercial entities with strict focus on profit, market dominance and control. You cannot exchange games between any two consoles from different manufacturers - indeed, you frequently cannot exchange games between two consoles from the same manufacturer. This is fundamentally a bad thing - it limits the usefulness of the devices, it unfairly dictates consumer behaviour by platform lock-in, and it raises artificial barriers of entry for software and content developers. It was the purpose of this thesis to evaluate how an open console system could potentially be developed. There are two fundamental approaches to solving this problem:

Figure 1 - The Microsoft Xbox

I. Hacking an existing console.

II. Developing a new console.

It was decided, having performed an extensive review of existing technology and available systems, that the most useful avenue of research was in the latter approach, building a new console from scratch. The former approach, modifying an existing console, was rejected for numerous reasons, some of which being that such an exercise would:

A) Be legally difficult, due to the many convoluted and unjust laws in Australia regarding copyright, intellectual property and the activities involved in modifying an existing electronic device. These won't be discussed here, since as matters of law they are insidiously complicated, but any of [1], [2] or [3] provide a good introduction.

B) Be largely useless as a commercial exercise, since it would not compare existing consoles against original devices.

C) Be heavily contingent on the availability of appropriate technical expertise and community knowledge, most of which can only be gleamed by reverse engineering, which may then fall under the problem noted in point A.

D) Not be considered to contain sufficient original work.

1.1 Developing a New Console

The hypothesis for this thesis was that modern computer technology has advanced so much in recent years that it is now conceivable for everyday people to develop their own game consoles.

An example of a "home-brew" console is the XGameStation [4] (pictured right), developed by Nurve Networks, designed as an educational console for would-be developers. It sports typical television outputs, serial inputs for joysticks, and a parallel port for direct programming with a PC. It is sold in kit form for $199US, which includes the board itself, a CD containing reference material and development tools, and the necessary adapters and peripherals to operate the device. As a console it is hopelessly underpowered by today's standards - it is optimistically approaching the capabilities of the original PS (PlayStation), without the more advanced features such as hardware accelerated 3D. But it does demonstrate that a console can be built cheaply, using standard parts and software such as BASIC and gcc. Unfortunately, it is immediately useful only for those who enjoy tinkering with such things - it would have absolutely no appeal to any normal gamer.

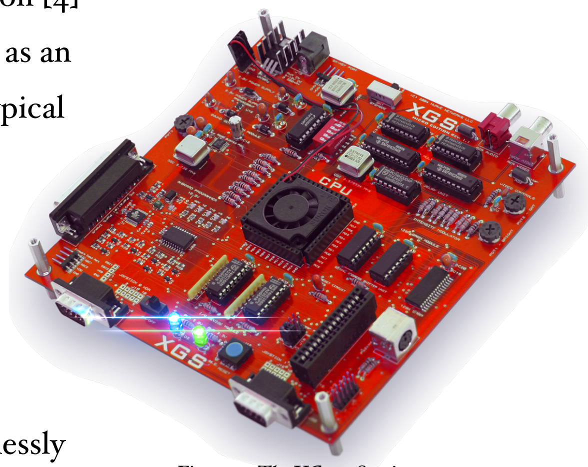


Figure 2 - The XGameStation

Figure 3 - The Gamepark GP2X

Another example is the GP32 [5] and the pre-announced GP2X (pictured left), a pair of portable consoles from Korean manufacturer Gamepark [6]. Both are built around Linux. They feature a colour screen and pleasant, standard form factor. It is not a pure home-brew console, however, as it is built by a small Korean electronics company, in relatively large volumes (150,00+ units sold already) and using an entirely proprietary custom design. It is difficult to acquire, and expensive relative to the dominant commercial consoles - e.g. PSP (PlayStation Portable) and Nintendo DS. It does lower the bar, however, to portable console development. And it's also a very interesting platform, given it is completely open, on which to explore the capabilities of portable consoles.

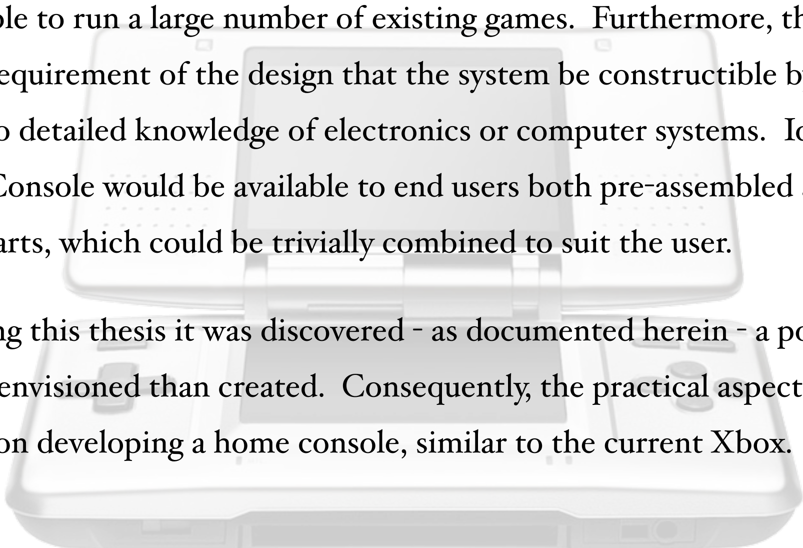
Figure 4 - Generic Arcade Cocktail Cabinet.

A key point to be noted about existing commercial consoles, particularly in recent times - they have become much more like PCs (Personal Computers). While the original home consoles were proprietary and closed systems - built from either their more powerful arcade siblings or completely from scratch - modern consoles are built from off-the-shelf parts, using standard components and interfaces (e.g. built-in Ethernet on both the the PS2 [7] and the Xbox [8], as well as USB via adapters).

Figure 5 - A generic Media Centre PC Full Kit.

With consoles such as the Xbox being essentially a specially modified PC, the question naturally arises as to what the real difference is, and more-so why your average Joe cannot follow suit by building their own game console, using standard PC technology - cheaply, quickly and easily.

Given this precedence set by the major console manufacturers, it seemed it should be quite plausible to develop an open, standard, off-the-shelf games console. If possible it would be a portable console, encompassing a sufficiently small form factor and LCD screen. It should run a standard, open operating system - such as Linux - and in doing so hopefully be able to run a large number of existing games. Furthermore, this thesis considers it a requirement of the design that the system be constructible by someone with little or no detailed knowledge of electronics or computer systems. Ideally, the Open Games Console would be available to end users both pre-assembled and as a collection of parts, which could be trivially combined to suit the user.



However, during this thesis it was discovered - as documented herein - a portable console is much easier envisioned than created. Consequently, the practical aspect of this thesis was refocused on developing a home console, similar to the current Xbox.

1.2 Console Functionality & Purposes

Figure 6 - Atari 800

Originally, consoles were simple, single-purpose machines. The first consoles often supported only a few built-in games, with no options for future expansion. That was more than 20 years ago. Over those years, several major revolutions have occurred in the console world.

Figure 7 - Nintendo Entertainment System

The first was the adoption of removable cartridges by the first mainstream console, the NES (Nintendo Entertainment System) - pictured right - in 1985 [9]. This spawned the first real console ecosystem, with a vibrant 3rd party developer market. It's role in establishing today's business models for consoles and video gaming in general cannot be overemphasised.

Figure 8 - Sony PS one

The second revolution occurred with the release of the original PS, which - through use of a standard CD-ROM drive - was able to double as a music player.

The third revolution could be said to have occurred with the release of the Xbox and the PS2 (PlayStation 2), both of which featured internet connectivity for multiplayer gaming. This revolution will be concluded summarily with the release of the Xbox 360, which will extend the internet connectivity to encompass all manner of online activities, not just gaming - such as voice chat, online shopping, and other functions.

Figure 9 - Xbox Live Logo

What the next revolution will be is hard to say, but in the author's opinion is the coming convergence of the games console and the PC. High-definition televisions rival PC displays for resolution and quality, and future consoles will have all the equipment - internal & removable storage, networking & wireless - necessary to be used for tasks such as word processing, web browsing, email, and more.

This vision of a unified computing platform is contingent, however, on the interfaces similarly converging. This remains a critical problem with current consoles - without a keyboard or equivalent, they are largely useless for the vast majority of "serious" tasks one might apply them for.

With all these things in mind, the core functionality required by an Open Games Console remains purely gaming. However, other highly desirable functionality includes:

- Media Playback
- Audio/video chat
- Media Recording (i.e. TiVo functionality)
- Web Browsing

Beyond that, there are options for functionality such as word processing, although this is presently not a high priority for home consoles.

Figure 10 - Sony PlayStation Portable

2.0 Design

The first step in building the Open Game Console prototype was to decide what the exact aims were, in terms of capabilities and target audience. The original hope of the thesis was to build a portable console in the style of the Sony PSP or Nintendo DS. That is, a small handheld device with reasonable processing power, a quality colour screen, and suitable form factor. The research into such a system's design is documented in the first subsection below. As has been mentioned and will be shown, a portable console was deemed unachievable at this point in time. Thus, the second subsection below looks instead at designing a "home" console - similar to the Xbox or PS2.

2.1 Portable Console

The first aim in designing any embedded system is typical to determine the CPU and mainboard to be used. Subsequent to this, integrated peripherals such as a screen and inputs can be selected.

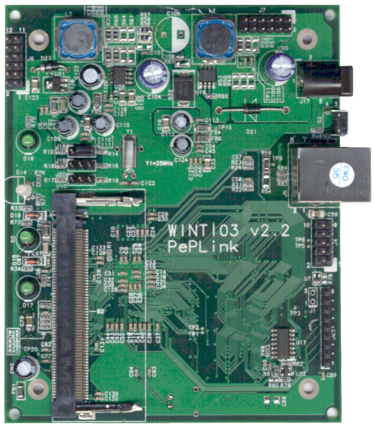


Figure 11 - PePLink Manga SBC

2.1.1 Mainboards

Initial research was done to find and enumerate all candidate embedded boards. These were then evaluated for suitability as a gaming platform. To cut a long story short, no suitable systems could be found - most had major drawbacks which immediately ruled them out of contention, such as entirely unreasonable cost, or simple unsuitability for use as a game console. Table 1 (next page) contains a list of boards and vendors considered, along with the reasons they were rejected. This list of candidates was garnered primarily from the article "Tiny SBCs for Embedded Linux based projects" from Linuxdevices.com [10], and supplemented by further research. All descriptions are copied verbatim from Linuxdevices.com [10], except where otherwise noted.

The ideal system would be simple, and provide only a few common interfaces - LVDS for LCD displays, USB (host) for numerous devices, and perhaps a few other essentials such as audio I/O and some generic I/O functionality (for custom additions that do not suit USB). Unfortunately, the economy and performance of I/O systems are inversely proportional to their generality, such that systems like USB are too expensive to be standard on small, price- and performance-sensitive embedded systems.

Name	Description	Reason
Acunia "Zingu"	This 2.7 x 3.6 in. SBC is based on an Intel Xscale i80200 processor with up to 850 MIPS performance. Includes up to 128MB SDRAM and 32MB Flash, plus built-in controllers for video, UART, AC97 Audio codec, PCMCIA, and I2C. Power consumption is under 2.5W.	Acunia no longer markets such devices generically (end solutions only).
ADS "Bitsy"	This 3 x 4 in. SBC details is based on a 206 MHz Intel StrongARM SA-1110 processor (plus SA-1111 companion chip) and consumes just 450 mW. Includes: serial, USB, audio, digital and analog I/O, a Type II PCMCIA slot, plus a 1024 x 1024 resolution colour LCD controller. ADS demonstrated several Bitsy devices (details) at a recent LinuxWorld show.	Single-unit cost starts at $2850 (for the dev kit), $500US+ for standalone boards.
Aleph One "Balloon"	Aleph One is shipping a one-ounce, one-watt, 206MHz StrongARM-based single-board computer (SBC) that comes pre-installed with embedded Linux and features an "open source" hardware design. Aleph One encourages device designers to freely use the design, and contribute back implementation details useful to others. Aleph One says its "Balloon board" is ideal for use in control systems, portable devices, wearable computers, instrumentation, and robotics. details.	£460 each.
AMC Technologies "NETdimm"	The NETdimm SBC module in AMC's 5.25 x 1.5 in. dimmPCI form-factor, based on a Motorola Dragonball processor equipped with up to 32MB SDRAM and up to 8MB Flash, and with built-in controllers for Ethernet, an LCD, 2 serial ports, and an SPI port. Runs uClinux. Other versions are available which replace the NETdimm's Ethernet and LCD functions with CANbus or digital and analog I/O.	$400US upwards. Looks like they require a PCI backplane to host them (i.e. not standalone).
Arbor Technologies "EmCORE-i315"	"ALi M6117C System On Chip @ 16MHz, compatible with 386SX-40 core, 4 MB EDO Memory, NE2000-compatible LAN 10 Mbps,16-bit Digital I/O, 1 x RS-232 port, 1 x RS-232/485 port, Parallel port, 1 x PS/2 Keyboard port. 2W peak power consumption, 100 x 71.6mm, 75g." [11]	Underpowered, unnecessary features, missing USB host functionality, etc.
Arcturus Networks "uCdimm", "uCsimm"	The SODIMM-sized (1.7 x 2.7 in.) uCdimm (details), pictured here, is based on a Motorola DragonBallVZ and provides 2 SPI interfaces, 2 RS232 ports, 22 digital I/O's, up to 640x512 LCD control, and 10 Mbit Ethernet. The older "SIMM-sized" (3.5 x 1 in.) uCsimm SBC (details) is based on a Motorola DragonBall 68EZ328 with 2.7 mips performance, and includes: 2MB Flash, 8MB DRAM, 21 digital I/O, serial, I2C/SPI, 10 Mbit Ethernet, and a 640x480 LCD controller.	$500US upwards (for dev kits), $200US upwards (for standalone boards). Cheaper kits don't include LCDs.
Axis "Developer Board"	A small form-factor SBC based on the 100 MHz Axis ETRAX 32-bit RISC system-on-chip processor. It is usable as either an ETRAX evaluation board or as a small embedded computer. Includes: 10/100 Mbit Ethernet, serial, parallel, RTC, 2MB Flash, 8MB DRAM, and 2KB EEPROM.	$275US. No obvious LCD support (certainly no LCD included).
C Data CompactFlash Computer	This tiny Linux-based computer fits entirely on a Type II CompactFlash (CF) card which can be mixed and matched with third-party CF-cards to create miniscule, modular Linux systems based entirely on CF cards. The module is based on a 66MHz Freescale MPC5272 SoC and includes 32MB SDRAM and 8MB flash, and runs uClinux.	Rumoured to be around $800US per evaluation board, but in any case doesn't appear to support USB host or include an LCD controller.

Name	Description	Reason
Cogent CSB637	A tiny SBC that measures 1.75 x 2.5 (63.5 x 44.5mm), and is based on an Atmel AT91RM9200, a low-power SoC (system-on-chip) with an ARM920T core that Atmel says delivers 200 MIPS. The Cogent board supplements the Atmel microcontroller's functionality, according to Direct Insight, offering interfaces that include 10/100 Ethernet MAC and PHY, USB, Dual SDIO, 4 UARTs, SSI, SPI, and CompactFlash Interfaces, an onboard LCD/CRT Controller. Also included are 64MB SDRAM and 8MB flash memory and an "efficient" 3.3V Regulator.	Thousands of pounds each.
CompuLab "586CORE"	A tiny (3.1 x 2.4 in.) PC-compatible SBC based on the AMD Elan SC520. Includes: 16-64 MB DRAM, 1-136M Flash disk, 69000-based SVGA graphics, 10/100 Mbit Ethernet, USB, 2-4 serial ports, PS/2 keyboard/mouse, IrDA, 32 digital I/O, RTC, sound, IDE/floppy interfaces, plus ISA and PCI expansion buses.	Evaluation kits are $1600US upwards. Individual boards are relatively cheap - $150US or so (upwards).
DDC Linux Rocket	Data Design Corp's claims its micro-miniature SBC provides a powerful Linux system on a truly tiny board. Based on a PowerPC 405GPr processor clocked up to 400MHz, the "Linux Rocket" includes DDC's custom PPC Linux kernel and flash filesystem, and targets kiosk, industrial monitoring and control, instrumentation, set-top-box, and vending machine applications.	$375 a board, only available in large quantities.
Embedded Planet "EP8260"	Physically, this PowerQUICC II (MPC8260) based SBC matches the footprint of a PC/104 module (3.6 x 3.8 in.) is not considered a PC/104 module. Includes: up to 32MB Flash and 128MB SDRAM, 10/100 Ethernet, and a PCMCIA Type II slot. Expandable via the PowerPC expansion bus.	$495 per unit (base price) for EP1000 boards (ARM based). All other products either $$$$ or not suitable.
Esfia M170S	A low-cost module for POS (point-of-sale/service) devices, RFID tunnel readers, biometric access control terminals, and other test, industrial, and medical applications, the ARM-based M170S measures 2.42 x 1.77 inches (61.5 x 45mm), costs $64, and is available with a wireless-enabled carrier board.	$2500US upwards ($65k plus for final boards).
Esfia M170P	A tiny ARM7-based SBC (single-board computer) that measures just 1.97 x 1.57 inches (50 x 40mm) and costs $64 in quantities of 5,000, the M170P targets rugged handheld devices, and is available with an evaluation kit that includes Linux.	Not suitable (no USB host, underpowered, etc). Significantly more expensive in small quantities.
Forth-Systems "DIMM-520", "ModNET50"	The tiny "DIMM-sized" (2.7 x 2.0 in.) DIMM-520 (details), pictured here, is based on the 32-Bit 133 MHz AMD ElanSC520 x86 system-on-chip. It includes: 64MB SDRAM, 16M Flash, PCI bus interface, 2 serial and 1 parallel ports, 100 Mbit Ethernet, and PC mainboard core logic. The ModNET50 (details) uses NetSilicon's NET+ARM system-on-chip to integrate a RISC processor, 100 Mbit Ethernet, 2 serial ports, RAM, Flash, and other functions on a tiny SBC.	Won't provide prices up-front, and in any case boards seem largely unsuitable (WindowsCE based, no USB host, unnecessary encumbrances such as PCI slots, etc).
General Micro Systems Spider	This standalone SBC measures 2.8 x 1.9 inches, boots from on-board flash, includes a DC-DC converter, and is based on an IBM PowerPC chip running either 400 or 800 MHz. A companion I/O card is available, with dual Ethernet ports and more. The Spider targets distributed control, telecom server blades, handhelds, and military/aerospace applications.	Promising, but won't provide prices up-front, and rumoured price is $400US for the base board.

Name	Description	Reason
Gumstix XM, BT, and Basix options	Gumstix has added extended memory and on-board Bluetooth options to its line of tiny gumstick-shaped XScale SBCs (single-board computers). It has also launched a new low-cost model priced at $99. The company now offers nine "Connex" and "Basix" SBCs priced from $99 to $189.	No USB host support or intrinsic LCD support, but cheap. Most likely candidate.
HCV "Wireless BlueMod"	This tiny (2.75 x 2.1 in.) SBC was specifically designed for Bluetooth wireless communication. It runs uClinux on a 32-bit 50 MIPS CPU with 8MB SDRAM and 2MB Flash. I/O includes serial, GPIO, USB (device), and connection to external adapters via a processor expansion bus.	$3000AU plus.
Inhand "Fingertip", "Elf"	The tiny (2.75 x 2.75 in.) Fingertip "PDA platform" (details), pictured here, is based on a 200 MHz Intel StrongARM 1110 CPU; it also includes: up to 32M Flash, up to 16M SDRAM, audio, 3 serial ports, SPI port, USB, 12 digital I/O lines, 320x240 LCD display/touchscreen interface, battery support, and CompactFlash expansion socket. Also based on an SA-1110 processor, the slightly larger (12 square in.) Elf (details) has a built-in PCMCIA slot, 16MB DRAM and up to 8MB Flash onboard memory, plus many of the same features as the Fingertip. InHand's Fingertip3 (details) is the company's first SBC based on an XScale processor.	Promising - has all the necessary features, but $2995US for the dev kits, ~$600US+ for single boards.
Intrynsic "CerfBoard"	A tiny (2.2 x 2.4 in.) SBC based on a 133 or 206 MHz Intel StrongARM 1110 CPU. Also includes: up to 16MB Flash, up to 8MB SDRAM, 16 digital I/O lines, 10 Mbit Ethernet, USB, serial port, audio CODEC, LCD interface, and CompactFlash+ socket.	$3000US for the ideal product, down to $1000US for the less so ones.
JUMPtec "DIMM-PC"	A family of "DIMM form-factor" (2.7 x 1.6 in.) PC-compatible SBCs. The DIMM-PC/586 (pictured here) is based on a ZF Micro ZFx86 system-on-chip processor and includes: 32MB SDRAM and 32MB Flash memory, plus interfaces for 10/100 Mb/s Ethernet, USB, serial (2), parallel, keyboard, floppy, and IDE. Additional models are based on 486 and 386 processors.	Cannot locate any information - most likely no longer manufactured.
Kontron X-board GP8	A highly integrated device in the very compact 67 x 49-mm X-board COM (computer-on-module) form-factor. Dubbed the X-board GP8, the SBC is built around an Intel Xscale 80219 microprocessor and Silicon Motion SM501 chipset.	Lots of nice looking boards, but a little large. Submitted request for quotes, no reply received.
LART	An "open licensed" small SBC (4 x 3 in.) design from the Technical University of Delft (Netherlands). It is based on a 220 MHz Intel SA-1100 StrongARM and includes: 4MB Flash and 32MB DRAM memory, serial and parallel ports, and bus expansion. Expansion boards provide: Ethernet, USB, keyboard, mouse, touch input, and video.	No longer manufactured.
Logic "Card Engine"	A compact (2.37 x 2.67 in.) family of tiny Linux-supported SBCs which include features such as onboard Flash (up to 32MB) and SDRAM (up to 32MB) memory, integrated LCD controller, touch panel support, serial, audio codec, Ethernet, Compact Flash and more. Sharp and Renesas processors are currently supported, and the SBCs include "production quality" BSPs and bootloaders.	Cool stuff - requested quote on numerous dev kits, but never received one.
SNMC "QS850"	A tiny (3.1 x 2.1 in.) networked PowerPC SBC based on a Motorola MPC850. Includes: 8-64 MB SDRAM, 2-16 MB Flash, up to 2 Ethernet ports, 3 serial ports, up to 64 channels HDLC, 49 digital I/O lines. Supported by SNMC's QSLinux Embedded Linux.	Web site no longer available - presumed out of business.
SSV DIL-40 DNP/5282	The first of a planned family of DIL-40 SBCs that measure 2.2 x 0.9 inches, matching the pin footprint of 40-pin "DIP" (dual-inline-package) ICs. The DNP/5282 is based on a 66MHz Freescale Coldfire processor, and comes pre-installed with uClinux.	£250+. Don't seem to offer anything that suitable anyway.

Name	Description	Reason
Strategic Test "Max-PC"	A matchbox sized (2.3 x 1.2 in.) SBC based on a 100 MHz 486 processor, plus 16MB RAM and 16MB Flash. Onboard controllers handle VGA, RS232 serial, parallel port, timers, keyboard, iRDA, and PCMCIA.	125 euros per board at the low end, 1650 euros plus for dev kits.
Techsol "Medallion"	A family of tiny (4 square inch) SBC modules. The HY7201 is based on a 60 MHz ARM-720T RISC processor, and includes 32MB of SDRAM and a 32MB DiskOnChip Flash disk, plus built-in controllers for 2 UARTs, CRT/LCD VGA, touchscreen, IrDA, USB (host and device), multimedia card, and GPIO.	Semi-proprietary CPU, $1000US+ for dev kit.
TQ-Components "TQM850"	A tiny (2.1 x 1.8 in.) SBC based on a 50 MHz Motorola PowerPC MPC850. Includes: up to 8MB Flash and up to 64MB SDRAM, plus dual-serial and dual-CAN (field bus) interfaces. Expands via 120-pin board-to-board connector on bottom.	Not much intelligible info on website (German), seems suitable, but no upfront prices.

Table 1 - Summary of Embedded Systems

As can be seen, the situation is not good. Many of these boards are aimed at embedded systems for industrial or commercial uses, with large scale manufacturing. Thus, while they may be cheap enough per unit (in large volumes), a single unit - especially a development kit - is usually prohibitively expensive. The one main exception is the boards produced under the Gumstix brand. These are aimed at hobbyists as well as commercial developers, and are both cheap and easy to work with. In addition to three brands of mainboards, the company provides numerous add-on boards which provided additional functionality and connectivity.

The Gumstix mainboards - as detailed by [12] - come with 200MHz (low end) or 400MHz (mid & high end) Xscale processors (an ARM derivative by Intel), 64 MiB of SDRAM, 4 (low end) or 16 (mid & high end) MiB Flash memory, and many connectivity options - including memory card interfaces, ethernet, stereo analogue audio in/out, Bluetooth, and more. They are roughly equivalent, in terms of performance, to the Nintendo DS.

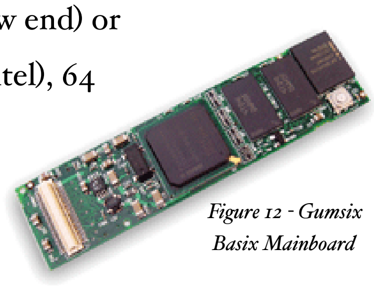


Figure 12 - Gumsix Basix Mainboard

Unfortunately, they have several key failings. The first is the lack of USB host support. A USB host chipset allows the device to connect to and use other USB devices containing USB "device" chipsets, such as gamepads, joysticks, mice and keyboards. The Gumstix boards only offer a USB device chipset (and not on the mainboard, either). A custom extension could be designed and built to provide USB host functionality, at the cost of:

A) Time and expertise - to design and assemble a small PCB. This is beyond the capabilities of the average person.

B) Size and weight - the additional daughter-board would substantially increase the size of the whole package, and to a lesser degree the weight.

C) Performance - the USB host controller would most likely have to be interfaced to the CPU via a generic I/O port, not a dedicated connection, which could seriously impact performance (both throughput and latency).

D) Software drivers would be most likely be required for the custom solution, which is far beyond the capabilities of the average person.

Another key problem with the Gumstix boards is the limited built-in video output support. They are not aimed at the market which would typically require such functionality, so for size and cost reasons do not contain any real dedicated video functionality. An LCD display can be connected to the boards via a custom daughter-board - the designs for some such are freely available online [13] - but, like the USB host functionality, this requires (depending on the exact LCD panel used) various degrees of custom circuitry, and far more expertise and equipment than the average person could be expected to have.

2.1.2 Display

Key to a portable console is a good screen. The importance of a good screen may not be immediately obvious at first glance. But when the requirements are thoroughly considered, the importance cannot be overemphasised. In priority order, the desired qualities are:

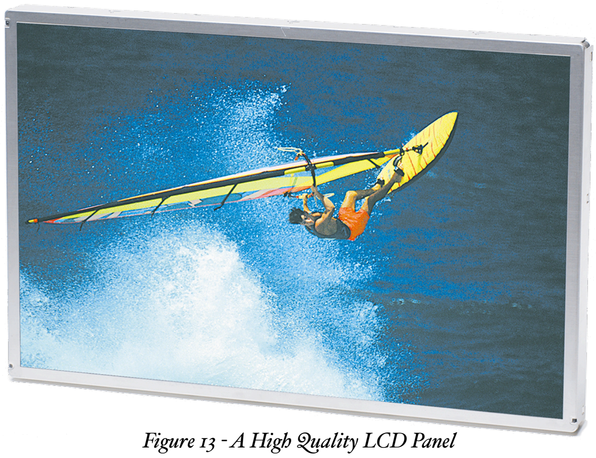


Figure 13 - A High Quality LCD Panel

1. **Contrast & brightness**. These are not usually the first qualities that come to mind, but they truly are the most critical. Portable game consoles are expected to be used anywhere, including areas of bright light and high glare. Thus, they require very high contrast and brightness - higher even than typical computer monitors - in order to be

visible at all times. Many consoles, such as the first generation of Gameboy Advances, suffered terribly at the mouths of critics for their inadequate screens. [14]


Figure 14 - Assorted LCD Panels

2. **Size**. Tiny screens make it difficult to use the device - particularly for those with visual impairments - as well as limiting the types of use. As proof by counter-example, consider the Tamagotchi [15] devices that were so popular several years ago. They all had relatively small screens, which were extremely low resolution (on the order of a dozen pixels square) and were generally monochrome. This perfectly suited their use. They were not suitable for just about everything else. Tamagotchis only required the user to see a small iconic representation of their creature, as well as a few status symbols. By comparison, a modern racing game requires high resolution for sufficient distance perception within the 3D game world, as well as room for speedometers, course maps, placement and ranking indicators, and more. For a console to be more than just a glorified Tamagotchi, it must have a suitably large screen.

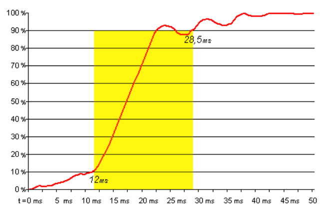


Figure 15 - LCD Response Time

3. **Response time**. This is the amount of time it takes to make a substantial change in intensity/colour of any given pixel. For LCDs it is typically within the range of 8 to 800 milliseconds. LCD monitors typically push the cutting edge at the bottom of that scale, while LCD panels for mobile phones and other devices often sit further towards the middle. A fast response time is necessary for rapidly changing images, to prevent blurring and ghosting. Standard broadcast TV requires a response time of 40 ms or less. The PSP is estimated to have a response time of at most 40 ms. A similar figure most likely applies to the Nintendo DS. The CNET News article "Response time: the faster, the better?" [16] serves as a good introduction to this topic.

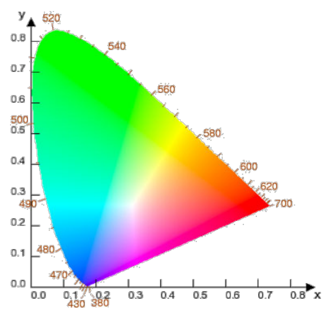


Figure 16 - Unclassified Colour Gamut

4. **Colour**. While not as important as size and contrast, colour is nearly as crucial for many uses. Colour adds an extra dimension to the display, allowing substantially more information to be conveyed to the user through it. For example, enemies within a game may share the same appearance, but be coloured differently based on their level or some other crucial attribute. And for non-gaming uses, such as watching video, high resolution colour is essential to provide life-like images.

Figure 17 - Money bag

5. **Price**. An expensive LCD makes for an expensive console, and an expensive console does not sell well, regardless of how good it may be. Overall quality of the LCD is typically proportional to it's price, which requires a careful trade off evaluation by designers. A fantastic LCD is useless in a device that no-one can afford.

6. **Power**. The screen typically uses the majority of the electrical power on a portable console. Poor battery life is one of the leading complaints against modern portable consoles (notably the PSP). So a very efficient LCD panel is necessary. And of course, high contrast and brightness are, unfortunately, directly proportionate to power usage. A typical LCD may use more than a whole watt by itself, while the embedded CPU and peripheral systems may use in the order of milliwatts.

Figure 18 - Generic DC Adapter

Figure 19 - Daylite-6.5 Rugged LCD Display

7. **Ruggedness**. Portable consoles are going to be dropped, sat on, scratched, and - especially if owned by small children with short tempers - generally beaten about. A tough screen is essential. And not just with regards to sharp impacts or pressure - scratching is perhaps the most common form of LCD damage on a portable device. Most LCD panels are not designed with this firmly in mind, and consequently fare very poorly when handed to children. It is a common criticism, for example, that the PSP is not suitable for children for this reason.

One key problem with LCD panels for the hobbyist is availability. LCD panels have traditionally been very expensive, relative to their usefulness to the hobbyist. Consequently, they are usually only produced in large quantities for commercial customers. Those that do filter down to the hobbyists are usually pulled out of an existing device (e.g. an old PDA, game console, mobile phone, etc) or are surplus items from larger manufacturing runs, discounted and bundled off to small distributors.

One such distributor is 4-star Electronics [17], although their slogan is something of a warning - "The #1 Source for Obsolete Integrated Circuits & Obsolete Semiconductors". Unfortunately they have a $300US minimum order policy, which immediately rules them out for any single-unit purchases. Similarly, Horizon Technology [18] have an excellent range, but have minimum quantities in the order of hundreds of units.

One notable distributor is EarthLCD [19]. They sell a wide range of LCD panels ranging from 1.5" to 15.1" in size, and priced from $6US to $1500US or more. As many of their products are surpluses, they are not necessarily cutting edge in many qualities, but they are easily available and in any quantity (up to the number in stock, of course).

As a rough indicator, some of EarthLCD's more suitable products are shown in the table below.

Name	Specs	Price (US$)
ACX705AKM-7 - Sony 240 x 160 2.7" Colour Reflective TFT Graphical Display with LED Frontlight	240 x 160 pixels LED frontlight Contrast Ratio: 13:1 512 colours Power Consumption: 47 mW Built-in 3-bit digital interface circuitry Module dimensions: 71.4mm x 52mm x 4.8mm (t) Effective Display Dimensions: 57.6mm (H) x 38.4mm (V)	1 - 19: $59 20+: $49
RNH942209R1A - SEIKO Colour STN 1.5" Cell Phone Display	128 x 128 pixels LED backlight 65K colours Module dimensions: 38.66mm x 37.39mm x 4.06mm Effective Display Dimensions: 27.94mm x 27.94mm	1 - 5: $17.00 6 - 99: $16.50 100 - 160: $14.50 161 - 720: $12.75 721+: $11.25
4LU4EB - Sharp B&W 383x234 Monochrome LCD	383 x 234 pixels Brightness: 230 cd/m2 Contrast Ratio: 50:1 Power: 12-24 Volts +DC Power Consumption: 4.3 W (at DC 8 Volt) Module Dimensions: 120.65mm W x 101.6mm H Effective Display Dimensions: 80.77mm W x 60.71mm H Weight: 1.361 kg Input Signal: Video (NTSC)	$79
LM32K102 - Sharp 4.7" STN 320X240 QVGA	320 x 240 pixels (no other specifications provided)	$115
EG9013FNZ1 - Epson Passive Transmissive 6.3" 640x480 Monochrome LCD	640 x 480 pixels CCFT backlight Contrast Ratio: 6:1	1 - 999: $29 1000+: $20
LM32019T - Sharp Graphic CCFL BSTN Transmissive, Backlit 5.7" 320x240 quarter VGA	320 x 240 pixels Brightness: 100cd/m^2 Contrast Ratio: 6:1 Power Consumption: 1.482 W Module Dimensions: 160mm W x 109mm H x 7.5mm D Effective Display Dimensions: 115.17mm x 86.37mm Weight: 160 g	$79

Table 2 - Specifications and Cost of Selected EarthLCD LCD Panels

These are unfortunately very typical of the kinds of displays that are available to the hobbyist. For comparison, the specifications of the PSP display is shown in the table below, as sourced from Sony's PSP product page [20].

Name	Specs	Price (US$)
Sony PSP LCD Screen	480 x 272 pixels 16.77 million colours Brightness: 180 cd/m^2 (battery), 200 cd/m^2 (AC adapter) Contrast Ratio: 200:1 (estimated) 109.3 mm diagonal (viewable area)	Unknown for screen alone, $249 for entire PSP

Table 3 - Specifications and Cost of the Sony PSP LCD Screen.

Clearly the LCD panels available to hobbyists are no match for the PSP's screen - none offer 24-bit depth (16.77M colours), most are relatively dim (less than 100cd/m^2, typically) and the contrast ratio is almost incomparable - typically on the order of 5 or 6 instead of several hundred. (Note: for reference an average LCD monitor has a contrast ratio of at least 400:1, with higher quality monitors achieving 1000:1 or more).

And another key factor that is not covered in the tables above, because it is only rarely and begrudgingly provided by manufacturers, is the response time of the LCD panel. For most of the panels listed, response times of 100 ms or more are typical. As mentioned, the PSP LCD has a response time of less than 40 ms (by most estimates). In practical terms, this makes a huge difference in the user's appreciation of the screen, and the ways it can be used.

In addition, the cost of hobbyist panels is exceptional in most cases. While still not even competitive - in terms of quality - with the PSP or the Nintendo DS, the higher quality LCD panels available are still $60US or more (in today's market, approximately $80AU). Given the whole console must be at least roughly competitive, price-wise, with existing commercial consoles, this leaves very little room for the remaining components. Indeed, combining even just the low-end Gumstix mainboards with one of the mid-range displays above yields a total cost of at least $160US, which is well above the $130US the Nintendo DS presently retails at, and not that far from the $250US of the PSP.

In terms of inputs, traditional portable consoles have been very limited. None have ever offered any kind of live video input, certainly because of the technical difficulties and probably also because there is no consumer demand for it. Video input possibly has uses for watching broadcast television on the device, but is otherwise limited. Ideally it could be used to record live video onto the device from a video camera or similar source, although at present the infrastructure requirements - including intermediate processing (e.g. compression) and storage - are not widely met in portable devices.

2.1.3 Audio

Beyond just the screen, the other core I/O requirement for a portable console is audio output. This is traditionally provided via at least built-in speakers, and usually a 3.5mm stereo jack. Indeed, for devices intended to be in public places the ability to use headphones or earphones is essential.

Figure 20 - BOSS IQ620 Speakers

The difficulty posed by most embedded boards is that they typically provide either no built-in audio capabilities, or they provide only a 3.5mm stereo jack. To provide built-in speakers, the mainboard may need to be modified, and additional software written to drive the custom speaker interface. Nonetheless, a device with audio output only via a 3.5mm stereo jack is acceptable.


Figure 21 - Generic Microphone

Very few include microphones or other audio inputs. As with video input, this is likely because there is minimal perceived use for it - portable consoles have never traditionally had audio input, and modern portable consoles manufacturers see no compelling reason to change that. Nonetheless, there are potential uses of such features - such as using the device as a Dictaphone, or for innovative games based around audio inputs from player.

Nonetheless, audio input, like video input, is a rather low priority for a portable console.

2.1.4 User Inputs

This is one area where there is clearly good news. The internal workings of the typical gamepad or joystick are rather trivial, with very little circuitry or complex assemblage. As such, they can be easily pulled apart and reduced to their core components, which could be integrated into the casing on a portable console. Furthermore, they are dirt cheap,

Figure 22 - Gravis GamePad Pro USB Controller

starting at $10AU for generic gamepads. For those requiring more advanced functionality, there is a huge variety of gamepads and joysticks, ranging from the simple generic types up to feature-packed and precise models that can cost several hundred dollars.

Additionally, generic buttons can be purchased from retailers such as Dick Smith Electronics for less than a dollar each, and wired up to the general I/O ports on an embedded system with minimal difficulty (although custom drivers may be required, which is far less trivial).

2.1.5 Software Installation

This essentially translates to "how do I get games onto the system?". Traditional portable consoles have used proprietary cartridges or discs (e.g. the Sony PSP UMD, pictured left). The mechanical drives for reading these make up a significant portion of the console's volume, and are a large issue for miniaturisation. Commercial manufacturers have been very hesitant to adopt more flexible means of running software - such as from Flash memory devices, external hard drives or over a network - because of the perceived risk of software piracy.

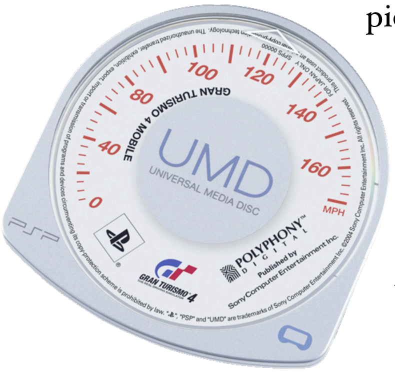


Figure 23 - Sony PlayStation Portable Universal Media Disk

Luckily for an Open Games Console, piracy is not a key issue. Thus, designers can concern themselves primarily with convenience and other factors. This leads to a preference towards either or both of two approaches:

A) USB storage devices (e.g. Flash memory sticks).

B) Internal storage with file transfer predominantly via networking.


Figure 24 - USB Storage Devices

The first approach minimised the size of the console, as it requires only a small USB port to fulfil it's function. However, having to keep an external device plugged into the console while it is in use is clearly a problem. Requiring the console be capable of temporarily storing the entire current software and it's data is difficult - large amounts of memory is both expensive, power hungry and negates the physical space savings.

Figure 25 - Apple iPod Nanos

The second approach requires some kind of internal storage - ideally Flash memory - which can be read or written to via networking (or through some similar means). Several gigabytes of Flash memory can be compressed into a chip the size of a postage stamp - for example, the 2GB chips used in the tiny iPod Nano (pictured left) from Toshiba are a mere 20 x 12 mm and weigh just half a gram [21] - so physical size is not a significant issue. The problem then becomes how to get software and data onto the internal storage. However, given that a modern portable console should ideally have wireless networking anyway - for multiplayer gaming - this can be done quite easily. Provided, of course, the owner has access to a PC or similar distribution point with the appropriate wireless access.

Internal storage also has the very significant advantage that it does not require the console user to carry any external media. The portability of consoles that require carry cases for their media is dubious at best.

2.1.6 Casing

Of course a vital component of a portable console is the casing. It needs to be aesthetically pleasing, as it will always be within the user's vision while in use, even if only the periphery. It also needs to be functional, being rugged and resistant to everyday wear and tear, as well as comfortable to hold.

Figure 26 - Venus 669 Black Cube Case (MiniITX)

The easiest way to start is by looking at the base line of cases, which is to say a box, literally. Generic plastic or aluminium cases are readily available, in various appropriate sizes and dimensions, from places such as Dick Smith Electronics, Tandy, or other such stores. Indeed, many hardware stores may stock something suitable also, although likely under the guise of a toolbox or storage container. These are cheap and serve reasonably well, but are certainly not ideal - a rectangular box with sharp edges is not comfortable to hold in the manner of a games console.

More suitable cases are harder to find - the market for open game console cases is minimal, given no such devices yet exist. An alternative, however, may be to make use of the substantial market in protective cases for existing consoles. Both the PSP and the Nintendo DS have numerous 3rd party hard cases designed to fit snugly around their form factor, any of which could be suitable for housing an open console. They are reasonably cheap, too - less than $30AU, typically.

Figure 27 - PSP Case

2.1.7 Power

An inescapable problem with portable game consoles is power. This was considered in detail in the literature review prior to this thesis, and so won't be covered in detail here. Suffice to say that good quality batteries can be very expensive and difficult to acquire, but the large number of discarded mobile phones makes for a large salvage market.

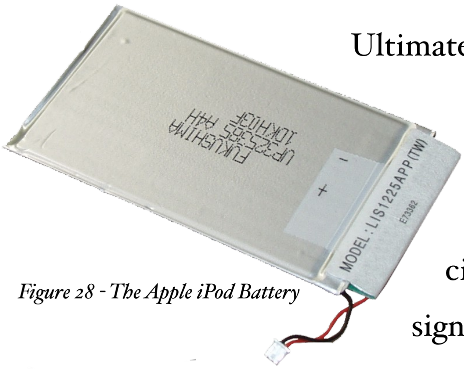


Figure 28 - The Apple iPod Battery

Ultimately standard batteries could be used - e.g. AA NiMH rechargeables - but their geometry is not optimal for a size-conscious device. The ideal battery is large but very thin, and a regular rectangular shape, for efficient use of space. The wasted space due to the circular nature of AA's reduces their effective power density significantly.

2.1.8 Software

The original presumption was that Linux would be used as the OS for the device, whatever it ended up being. Linux is well suited to embedded systems - indeed, all the Gumstix systems come with Linux pre-installed, and Linux is the only supported OS.

While the advantages and disadvantages of Linux as a whole will be discussed in further detail in later sections, we will consider here it's use as it relates to embedded, portable devices.

First and foremost to be considered is what OS's *can* be used on an embedded system. Linux is an obvious candidate, as is

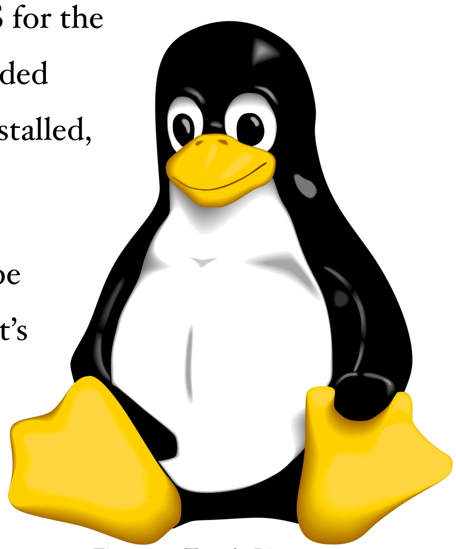


Figure 29 - Tux, the Linux mascot

NetBSD - both have a long history in embedded systems. There are also several Unix-like OS's that suit - or are even designed specifically for - embedded systems, such as Wind River's VxWorks, QNX, Symbian's SymbianOS, etc. Unfortunately, all of these are commercially orientated and all cost substantially more than what would ideally be spent on the OS - which is of course nothing. There is also the issue of software - SymbianOS supports Java, as it's designed for multimedia mobile phones, but Java is not suited for gaming, nor are there many premiere games written in Java.

From a software point of view, a Windows-compatible OS is desirable, as Microsoft's Windows platform has the greatest share of the gaming market. However, Microsoft do not provide any OS's suitable for resource-limited embedded systems such as a portable game console, and certainly do not do so freely. Consequently they are, regrettably, not even a candidate.

And so it seems ultimately to come down to Linux and NetBSD. The BSDs are more mature, provide greater stability and security, but are not quite so well supported by 3rd party software and hardware manufacturers. All BSDs support a Linux compatibility layer, which provides missing interfaces that some Linux software may expect, but this compatibility layer requires a substantial amount of storage space, and does not come completely free - it does incur at least some overhead, reducing program performance.

In any case, if Linux is going to be emulated, it certainly seems to make much more sense to just use Linux directly. Consequently, Linux appears to be the clear choice for a portable game console.

2.1.9 Conclusion

Within the pre-determined budget limit of $500AU, it is clearly difficult to produce a competitive portable games console. To be superior to any current commercial portable consoles is seemingly impossible.

Two things must happen before this dream can be realised. First, a full-featured embedded system must be released, with a low price and easily accessible to hobbyists. The Gumstix systems are very close to this goal, and given the feedback on their public forums, must certainly be considering these potential markets.

Secondly, and most importantly, LCD panels must become much cheaper, and be far more readily available. At present it seems impossible to obtain an LCD panel with the same brightness, contrast, resolution and depth as the PSP screen. And even then, they must be affordable - in today's market the price of such a hypothetical screen can be extrapolated as being extremely high; $200US or more. Completely unacceptable.

Hopefully, given the pervasiveness of the PSP and the future portable game consoles following in it's footsteps, the high quality parts used for their manufacture will become more publicly available.

2.2 Home Console

A home console is much closer to traditional hobbyist projects - such as home entertainment PCs, in-car PCs, and popular hardware hacks (e.g. putting a PC in a toaster). Consequently, the area is much more researched, and the limits much more thoroughly defined and tested. Many websites exist devoted to small form-factor mainboards (e.g. MiniITX, MicroATX, etc) and their uses, such as those mentioned. Consequently, as will be shown, designing a home console is far easier and a working prototype more likely to be constructible.

The first place to start, as before, is with a choice of mainboard.

2.2.1 Mainboards

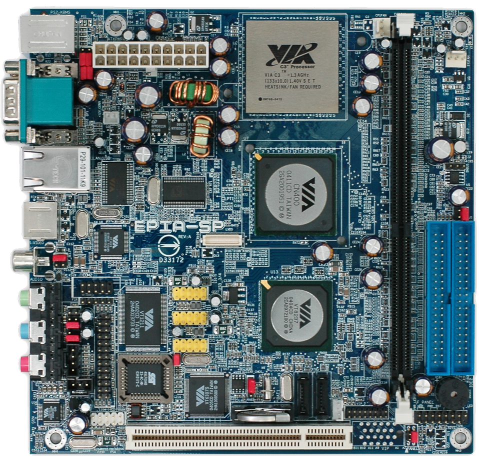


Figure 30 - VIA EPIA-SP mainboard

There are quite a range of possibilities in this space. First and foremost are the popular MicroATX and MiniITX form-factors. The former packs more or less an entire normal ATX mainboard into a board less than 25cm square. The latter makes some compromises with regards to power and extensibility, packing a reduced system into a board less than 17cm square.

More recently there has been the announcement of the NanoITX form factor, pushed heavily by VIA Technologies. Boards of this size are comparable in functionality to the MiniITX boards they are descendent from, but fit into an area less than 12cm square. Depth issues aside - they still require large heatsinks and obtrusive components on top of the board - these dimensions

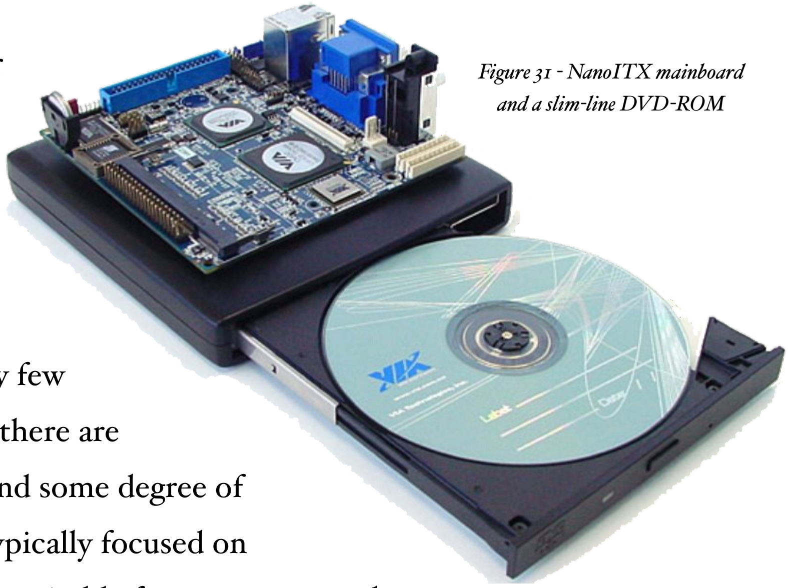


Figure 31 - NanoITX mainboard and a slim-line DVD-ROM

are getting into the realm of feasibility for portable game consoles, and are more than ideal for home consoles.

Unfortunately, VIA Technologies is the only manufacturer at present to have announced NanoITX boards, and the very few that are available start at $390US. While there are numerous other boards of a similar size, and some degree of standardisation amongst them, they are typically focused on industrial control applications, and are not suitable for a games consoles.

Boards using the MiniITX form factor, however, have been shipping for some time, and are relatively easy to obtain from computer retailers online.

Other mainboard possibilities include some of the more powerful boards considered in the previous section on portable game consoles. Unfortunately, they are still discarded immediately due to their high cost and limited availability.

Another alternative is the mainboard used inside Apple Computer Inc.'s Mac Mini. This board is approximately the same size as the NanoITX boards previewed by VIA, but much thinner, allowing a DVD burner, hard drive and DDR SODIMM to fit into a case less than 5 cm tall - by comparison, the heatsinks on VIAs NanoITX and MiniITX boards are nearly 4 cm by themselves. It is also more powerful, being essentially equivalent to a full-blown consumer laptop, such as Apple's iBook range [22].

Figure 32 - The Apple Mac Mini

Unfortunately, the only way to obtain a Mac Mini mainboard is by obtaining a Mac Mini. Starting at $720AU and going up to $1000AU or more, this is clearly not an economical option, despite it's attractiveness.

Table 4 (next page) enumerates just a fraction of the options available at present, focusing primarily on the MiniITX (or smaller) form factor. All descriptions are in the authors own words, except where otherwise noted.

Name	Description
VIA EPIA	A range of boards containing VIA Eden or C3 x86-compatible processors, integrated graphics controllers (some with MPEG-2 and MPEG-4 acceleration), onboard Ethernet (typically 100BaseT, 1000BaseT available on some models), stereo audio output and line input (some models offer 5.1 output, and/or digital output via RCA in S/PDIF format), VGA output, S-Video output (on most models), DDR SDRAM slot(s) (most models), PS/2 keyboard & mouse inputs, USB 2.0 connectors and headers, PCI slot(s) (most models), ATA/133 connectors, SATA connectors (some models).
VIA VT-310DP	A specific board, similar to the EPIA models, distinguished by it's dual processor configuration, providing two Eden-N processors. Integrated graphics accelerator (including MPEG-2 and MPEG-4 acceleration), 2 x DDR SDRAM slots, 1 x 1000BaseT Ethernet port, 1 x 100BaseT Ethernet port, USB 2.0, ATA/133, SATA, PCI, MiniPCI, VGA output.
Kontron ETX	A wide range of small-profile ETX boards, typically around NanoITX size, available with a wide range of CPUs - from Intel Pentium MMX to Celeron to Pentium M brands, as well as the STPC Elite processor (not x86 compatible). Most boards support older SDRAM, provide multiple USB 2.0 ports, many have LVDS connectors in addition to VGA outputs, serial ports, optional DVI outputs (on some models), EIDE connectors (some models), onboard 100BaseT Ethernet, PS/2 inputs and analogue audio line-level I/O. None provide actual connectors onboard, and it is not clear whether the boards are capable of being self-sufficient, or whether a baseboard is compulsory.
Kontron ETXexpress (pre-announced)	"Based on the soon to be release COM Express standard from the PCI Industrial Computer Manufacturers Group (PICMG), ETXexpress products are next generation embedded modules that bring advanced technology to tomorrow´s applications. Built around serial differential signalling technology, ETXexpress modules incorporate interfaces for PCI Express, Serial ATA, USB 2.0, LVDS, Serial DVO, and much more into a 95 x 125 mm small form factor embedded module. ETXexpress modules provide the highest available performance on the smallest state of the art embedded modules. Additionally, by following the modular concept for embedded design, ETXexpress modules safeguard R&D investments and lower total cost of ownership." [23]
Kontron PC/104	A wide range of boards in a similar style to their ETX boards, but based around the PC/104 bus standard. Wide range of processors - all those offered by the ETX boards as well as AMD Geode's, STPC VEGAs and more. Most boards provide LVDS connectivity, multiple RS-232 serial ports, support older SDRAM, onboard 100BaseT Ethernet, analogue audio output, USB 2.0 or USB 1.1 and PS/2 inputs. As with ETX boards, none come with actual connectors onboard - just headers or similar.
Kontron EPIC	A pair of boards, one with an Intel Pentium M CPU, the other with an Intel Celeron. Both come with numerous serial ports (RS-232 and RS-422), integrated hardware graphics acceleration, 6 x USB 2.0 ports, onboard 100BaseT Ethernet, 1 x ISA and 1 x PCI sockets, VGA output, LVDS connectivity, DVI connectivity, 1 x LPT port, multiple GPIO pins, analogue line-level audio I/O, and DDR SDRAM for Pentium M models, older SDRAM for Celerons. Unlike most other Kontron boards, these provide onboard connectors for most of their functionality.
Kontron JRex	A range of boards with identical mechanical layout for painless upgrading, with CPUs ranging from VIA Eden and C3s to Intel Pentium Ms. Similar features to the EPIC or PC/104 boards, but without ISA connectors, and with the onboard connectors like the EPIC range.
Kontron 786 & 886	MiniITX form-factor boards with a high power focus. Available with Intel Pentium III, Pentium IV, Pentium M or Celeron CPUs, they all feature onboard Ethernet (either 100BaseT or 1000BaseT), USB 2.0, ATA/133, SATA/150, hardware RAID 0/1 support (SATA only), integrated Intel graphics chipset, 5.1 Dolby Digital audio output, Compact Flash socket (some models), LVDS and DVI connectivity, 1 x PCI slot, 1 x AGP slot (some models), multiple RS-232 connectors, DDR SDRAM (most models) and PS/2 inputs. All boards come with standard backplane connectors for most functionality, in typical fashion for MiniITX boards.

Name	Description
Arbor Technologies EmETX	A range of five boards of similar specifications, with processors ranging from Intel Pentium Ms to VIA Edens and Transmeta Crusoes. DDR SDRAM (in some models; older SDRAM in others), VGA and TTL/LVDS outputs, TV-out (some models), onboard 100BaseT Ethernet, 4 x USB 2.0 ports (some models, 4 x USB 1.1 on others), 2 x RS-232 serial ports, IrDA, PS/2 inputs, 2 x ATA/100, integrated hardware graphics acceleration and 1 x parallel port. No actual connectors on any of the boards; boards are designed to slot into a carrier baseboard. It is not clear whether or not the boards are actually self-sufficient, or whether this baseboard is required.
Arbor Technologies PC/104	Huge range of PC/104-bus compliant boards with similar specifications to the EmETX range, with the notable addition of Compact Flash connectors on most of the PC/104 boards, as well as ISA and/or PCI slots. Also available with STPC Atlas processor.
Axiomtek PC/104	A range of PC/104-bus compatible boards, using CPUs ranging from VIA Edens or C3s to AMD GX1s to STPC 486-compatible Consumer IIs. Most boards feature 100BaseT Ethernet (some with dual), a single SDRAM SODIMM slot, Parallel and Serial ports, VGA output, PS/2 inputs, LPT ports, Compact Flash socket (some models), TTL/LVDS output (some models), and analogue line-level audio output (some models). Most have basic connectors onboard, but more advanced features (e.g. LVDS) are only headers.
Axiomtek SBCs	A range of four SBCs (Single-Board-Computers), two with MiniITX form factors. A range of CPUs from Intel Pentium IIIs, Pentium IVs, Pentium Ms and Celerons to VIA Edens and C3s. DDR SDRAM (most models, others have older SDRAM), ATA/100 (one model with ATA/133), SATA/150 (one model), PS/2 inputs, RS-232/422/485 serial ports (most models), USB 2.0 ports (one model with USB 1.1 only), onboard 100BaseT Ethernet, LPT port, IrDA port, VGA and LVDS outputs, analogue line-level audio I/O, Compact Flash socket (some models). Most core functionality has onboard connectors, more advanced functions are available only via headers.
Axiomtek STX/STB	A range of boards with similar specifications to the SBC boards, but without any onboard connectors - just headers. Some models are significantly smaller, however - less than 100mm square. Some models also provide PC/104 buses, as well as ISA and/or PCI slots. Many also provide numerous generic digital I/O pins.
Axiomtek AX	A family of compatible modules, designed to be connected together to form a full-featured system, with specific functionality. Uses the PC/104 bus for inter-board connectivity. Interesting modular approach, but available CPU modules are limited to 386 and 486 compatible processors, operating at very low clock rates.
iBASE ET	A range of ETX CPU boards in a very similar style to those from Axiomtek or Arbor Technologies; i.e. a range of processors from Transmeta Crusoes to VIA C3s to Intel Pentium Ms. Features include TV-out (some models), onboard 100BaseT Ethernet, IrDA, Parallel port, RS-232 serial ports, ATA/100, USB 1.1 or 2.0 (some models), VGA and LVDS output, etc. As with other ETX boards, no mechanical connectors are included on the board; only the ETX bus interface.
iBASE 3.5” SBCs	Two tiny SBCs designed for PC/104 or PC/104+ systems. One provides a 300MHz AMD Geode GX1-300 processor (with older SDRAM), the other suits Intel Pentium Ms up to 1.6GHz (with DDR SDRAM SODIMM slot). Both feature onboard 100BaseT Ethernet, USB 1.1 (Geode) and USB 2.0 (Pentium M), RS-232 ports, IrDA, Parallel ports, VGA and TFT TTL (Geode) or LVDS (Pentium M) output, etc. As with all PC/104 boards, no actual connectors are included onboard, just the PC/104 buses.
iBASE 5.25” SBCs	A wide range of SBCs similar to the 3.5” models, but in most models with additional features - such as Compact Flash sockets, 1000BaseT Ethernet, room more additional RAM, improved integrated graphics, analogue line-level audio I/O, etc. Some boards have certain connectors onboard (such as for audio), although again are largely PC/104 bus based.
iBASE MB	A range of MiniITX and MicroATX boards, with very similar functionality to those by other manufacturers.

Table 4 - Specifications of a Small Sample of Mainboards Suitable for a Home Console

Other notable vendors of similar products include Commell, Toshiba & Transmeta.

The PC/104 family of standards are an interesting approach to modular design, which is of course of great interest. A modular design by nature opens the system, making it easier for numerous manufacturers to produce compliant products, and easier for consumers to pick and choose amongst these to meet their individual requirements.

Unfortunately, the PC/104 standards utilise old technology (ISA) which is not really up to par - performance wise - with the requirements of a game console. Additionally, while there is a massive market for PC/104 products, the vast majority - as shown in the previous table - are aimed at industrial control, POS (Point of Sale) or similar applications. Very few include significant hardware acceleration for graphics, sound or any other key aspects of gaming. Some manufacturers are trying to push upwards into larger markets by shipping more and more powerful products based on PC/104, but there are limits due to the legacy technologies mandated by the standards.

By way of comparison, because the MiniITX and MicroATX form factors are developed by PC manufacturers, seeking to push their way down into the embedded space from a typical PC background, the focus is on high performance, particularly in the area of graphics. They favour standard connectors (e.g. USB 2.0) more than embedded manufacturers, and are faster in adopting new standards such as SATA. Consequently, they are both more powerful and more widespread in the consumer market, and thus likely to become the dominant designs in future.

Thus, for the practical aspect of this thesis the decision was made to adopt the MiniITX form factor. In addition to the points made previously, the emphasis in this decision was primarily with regards to size, availability and cost. MiniITX boards can be obtained for less than $200AU, they are reasonably widely available from computer retailers, and they are the smallest boards available, given the restrictions imposed by the two previous priorities.

There are numerous manufacturers shipping MiniITX boards, the most notable of which are included in the table earlier. These manufacturers encompass a wide range of target markets and uses, from the dumb terminals and control applications already served by the PC/104 boards, up to the PC market.

To narrow the selection further amongst individual MiniITX vendors, the importance of availability was increased, and cooling requirements were considered. For this thesis it was not suitable to have wait several weeks for a board to be shipped internationally - this requirement immediately ruled out some of the lesser-known manufacturers, leaving primarily VIA Technologies and Kontron.

Ideally, the board would require no active cooling - any device which is going into the living room should ideally be completely silent in all modes of operation, to prevent disturbances to watching TV and other key activities that take place there.

Thus, the ideal board would not use fans or any other moving (or otherwise audible) means of maintaining a safe operating temperature. Since a home console could be used in any manner of placements - typically crammed into a claustrophobic home entertainment closet - it must be capable of not only cooling itself passively, but also absorbing the heat generated by other devices nearby. This ruled many of Kontron's offerings (and a few of VIA's) out of contention, as most required active cooling as a result of using high-power CPUs such as Intel Pentiums.

VIA Technologies, on the other hand, generally favour their own x86-compatible CPUs, under the Eden and the C3 brands. These are specifically designed to consume much less power than Intel or AMD processors, and consequently VIA's boards are much more suited to cramped, hot spaces.

And perhaps the biggest differentiator between VIA and Kontron's offerings is support for Linux - VIA provide Linux drivers freely for all the key devices on their boards, whereas Kontron do not - they offer them only to supported clients as part of their Board Support Packages.

While Linux (and many other operating systems) will undoubtedly run on the Kontron boards, advanced functionality such as hardware accelerated graphics may not be supported, or may not perform optimally. In any case, good vendor support (including quality, available drivers) is critical to the average user, who may need help building and configuring the system, or in the case of troubleshooting.

With VIA now chosen as the intended vendor, the choice comes down to which specific board. They offer a range of approximately a dozen appropriate boards, with similar specifications - 600 to 1300 MHz CPUs, SDR or DDR SDRAM, multiple onboard USB host interfaces, integrated graphics accelerators (some with accelerated MPEG2/MPEG4 decoding), etc.

For our intents and purposes, they are all more or less equivalent. The individual in question might favour one over another for a particular feature (e.g. additional USB ports, LVDS support, etc), but even at the low end they meet the fundamental requirements for a game console. Of course, the higher end models feature higher performance, which is a critical attribute, and will dictate exactly which games can be run on the system.

For demonstration purposes an EPIA-SP8000E was acquired. It represents the higher end of VIA's range, and is one of their more recent designs. It can be purchased for around $300AU. The cheaper alternative models mentioned can be purchased for as little as $180AU.

For reference, the current Xbox or PS2 can each be purchased for approximately $200-$250AU, depending on bundling and other special offers.

With a board now selected, compatible support hardware could now be selected.

2.2.2 Display

The screen is not an intrinsic part of a home console, as it is for a portable. It is still expected that a home console will connect to any TV commonly found in todays households. There are four main ways of connecting to TVs - coaxial cable, S-Video, composite video and DVI. Nearly all computers - including the embedded systems considered previously - with any sort of TV-out capability support S-Video and composite video (a.k.a. RCA video). More modern computers support DVI as the output of choice for any video, whether a TV or computer monitor, although DVI support on TVs is limited to higher-end modern sets. Also, most embedded boards are not powerful enough to effectively drive a high definition DVI output, and so do not provide DVI output.

VIA's MiniITX boards all support VGA output - VGA to DVI adapters are commonly available for around $20AU - and many support component video and S-Video. The SP8000E supports all three (although not simultaneously).

Video input is not a traditional feature of consoles, but the possibilities are immense. TV recording devices such as the popular TiVo® are obvious candidates for integration with home consoles. Unfortunately, video input - and more importantly, TV tuning - are not built-in features on any system surveyed in this category. TV tuner cards are widely available starting at approximately $60AU for analogue receivers, up to several hundred dollars for highest quality digital receivers. Video input was not implemented for this thesis, as it is not central to the aim.

An interesting option with video capture, however, are USB-based devices that are fairly widely available. These could easily be connected to the Open Games Console as an after-market accessory, using the simple USB 2.0 interface.

2.2.3 Audio

In terms of audio, there are limitations that come with small form factors. Audio has not been a strong traditional focus on embedded devices - indeed, very few support 5.1 or digital output. Many of VIA's boards provide digital 5.1 output, but on the same physical RCA connector as component TV output, forcing you to choose one or another (although S-Video can be used instead). Most do provide audio input if they provide output, which is a useful feature to have standard - possibilities for audio input include original gaming titles based on players generating noises (such as karaoke), as well as "serious" software such as audio conference, VoIP, etc.

2.2.4 User Inputs

The traditional method for controlling a home console is via a gamepad. Today's gamepads contain a dozen or more buttons, typically at least two joysticks, a direction pad, and numerous other features. They have been so successful in the current generation that the vast majority of PC gamepads have followed suit. Thus, it is very easy to obtain - cheaply - the same sort of gamepads that today's consoles provide.

In fact, Microsoft's Xbox 360 (to be released later this year) uses USB 2.0 as it's standard input interface. It's primary corded controller is thus a USB device, and has in fact already gone on sale for use on standard PCs, and is now available for as little as $32US.

In addition to standard gamepads, many consoles also support alternative inputs. Light guns were once very popular, but have not made an appearance on the current generation of controllers. There are a few PC light guns available, such as those by ACT Labs, but they are both rare and expensive - $80US for ACT Labs', for example. They typically require explicit support in games to be used effectively. They also require CRT displays, not LCDs, in order to function. Whether this limitation extents to encompass plasma displays is not stated by the manufacturer. They were not considered for the practical side of the thesis for these reasons.

Other input devices include video cameras such as the popular Sony EyeToy. Although the EyeToy, when first released in November 2003, was hailed as revolutionising the arcade genre, it was not the first implementation of the idea - in 1999, for example, Intel released their Intel® Play™ Me2Cam [24] software and video camera, which worked in much the same way as the EyeToy. Unfortunately, it was discontinued in 2002 and no other product appears to have taken it's place, for Windows or Linux. There is an equivalent product call ToySight, presently available for Mac computers, but that is not much use for an x86-based console.

2.2.5 Software Installation

Traditionally home consoles have used cartridges, or more recently optical media such as DVDs. Many of the same principles and problems apply to home consoles as were previously discussed for portable consoles - notably the focus on restriction rather than convenience, to deter piracy. Again, an Open Games Console has the huge advantage of not being concerned with this, and so can focus on ease of use and functionality. It is becoming more essential for home consoles to support non-volatile writable media, for saving games, settings and other data. This used to be achieved using expensive, proprietary memory cards. Today it can be done cheaply and conveniently using USB storage devices.

Also, hard drives are very cheap. The smallest capacity even (widely) available today is 80 gigabytes, and these retail for less than $100AU [25]. For gaming alone this capacity is more than sufficient. For expanded uses (such as storing video content) larger drives are desirable, and can of course be used at the consumer's discretion.

For demonstrative purposes, given the prototype console does not have video capture functionality, several older hard drives were recycled. This avoided the additional cost of buying a hard drive, and is a good demonstration of what can be made of old hard drives that many people have lying around. Also, it is presupposed that the user would make heavy use of USB storage devices - such as Flash memory sticks.

In addition to support for USB storage devices, networking is a convenient and efficient method for transferring software and data. Nearly all the mainboards considered - including those evaluated for a portable console - provide onboard 100BaseT Ethernet. None provided 802.11 wireless, although such functionality can be added via add-on PCI cards or USB devices.

Last, but certainly not least, is the need for a DVD-ROM. If nothing else, this is necessary to play DVD videos, audio CDs and other such media. It was fully the intention to add a standard IDE DVD-ROM to the prototype. Unfortunately, practical problems arose with this, as documented in the Assembly section.

2.2.6 Casing

Unlike casing for portable consoles, there is a substantial market for attractive casings for MiniITX boards. Unlike a portable, there is little functionality required of the home console's case - it need only be small, of a regular shape amenable to home entertainment cabinets, and aesthetically pleasing.

Unfortunately, cases come at a cost. The cheapest the author could find started at $125AU. Some cost as much as $300AU. And the physical size of cases makes them expensive to mail interstate, and exorbitant to ship internationally, leaving the economical consumer with only what they can find locally. All in all, it makes little sense to use a case which costs more than the system itself.

Of course, alternatives are available. While a purpose-built case for the MiniITX form factor is ideal, with a bit of work the components can be shoe-horned into various other cases. For example, an old VCR or DVD player can be repurposed for the task. To test the feasibility of this, a VCR case was adopted for the prototype system. VCRs, being largely obsolete today, are easy to acquire cheaply or even for free, making them ideal.

One concern with VCR or DVD player cases is their profile - typically they are wide and relatively shallow. This poses a problem - most PC cases are thin and deep, and consequently most PC hardware is designed around this presumption. A standard IDE DVD-ROM is approximately 21cm deep (about the width of this page). A typical VCR case is no more than 30cm deep. When you start playing around with the numbers (i.e. MiniITX mainboard is 17cm deep, PSU is at least 15cm deep, etc) it becomes a problem. This problem is documented thoroughly in the Assembly section.

An additional but important final point; the case is often a substantial portion of the final system's weight. Many attractive MiniITX cases are metal, and can be quite hefty - ranging from a fair 450 grams up to 3.2 kgs or more! For reference, the entire PS2 weighs just 900 grams, and the current Xbox weighs 3.86kg. Clearly consumers will accept large and weighty consoles, but it is always preferable to aim for smaller and lighter designs. Heavier devices pose a greater risk of harming other devices or people (i.e. children), if they are dropped or shoved around.

2.2.7 Power

The power requirements for a home console are much easier to satisfy than a portable console. A home console has no strict need for batteries or similar self-sufficient power; it is both normal and sufficient to run directly from mains power.

There is one possible exception, however - the case where the system does not shut down when not in use, but rather sleeps. Most OS's can awake from sleep within a few seconds, making this mode of operation far more user-friendly than a cold boot for each use. User's may expect to be able to unplug the system while it is "off" (i.e. asleep), without it shutting down. Thus, a backup battery - or deep sleep (a.k.a. hibernation) - could be desirable.

The actual power requirements of most MiniITX (or smaller) systems is very minimal - typically less than 50W. The particular MiniITX model adopted for the prototype uses at most 20W. By contrast, the smallest typical PC PSU (Power Supply Unit) is 250W. Clearly overkill for a console's needs, even taking into account the power requirements of the hard drives and other peripherals.

PC PSUs can be acquired very cheaply and easily. Unfortunately, they are physically very large. It is for this reason that many MiniITX cases come with a low-profile PSU built-in (which helps to explain their high cost). Small PSUs, in the order of 60-120W, are reasonably easily available, but can be expensive - $40AU or more. Ultimately the PSU required is dictated by the desired case - if a generic PC PSU fits into the case, then it is ideal. If a smaller case is used, a smaller PSU will be required, with a corresponding increase in cost.

Additionally, PC PSU's with high power ratings require significant cooling, which means very powerful - and loud - built-in fans. As is documented in the Assembly section, this put an unfortunate end to the dream of a silent prototype.

2.1.8 Software

The OS is the biggest single piece of software, and the most critical - it defines what software (i.e. games) can be run on the console. The primary contenders are:

A) **Linux** - Completely open source and free (as in beer), there is a massive user community devoted to the OS. It is used in systems ranging from embedded networking infrastructure to industrial control systems to high end servers and more. It is certainly a capable OS for a home console, given a custom system.

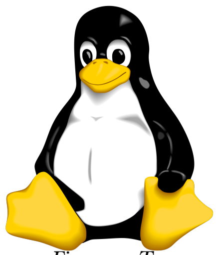


Figure 33 - Tux

B) **BSD** - Very similar to Linux, and being largely compatible with, the various BSDs are older and more stable than Linux, but do languish in terms of support for modern hardware. Also completely open source (even more-so than Linux) as well as free as in beer.

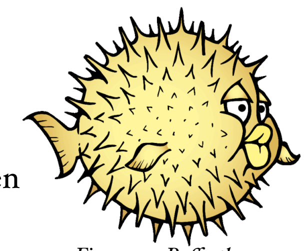


Figure 34 - Puffy, the OpenBSD Mascot

C) **Windows** - Fairly self explanatory; the dominant desktop OS, from Microsoft. Commercial, closed-source and relatively expensive, it is nonetheless the dominant gaming platform (even including existing game consoles). Hardware vendors tend to support Windows as their primary OS, making it the best bet for support and functionality.

Figure 35 - Windows XP Logo

D) **MacOS X / Darwin** - Not quite yet available for "standard" x86 systems, but a worthy of consideration both for PPC-based systems and in the case that it does become available for the x86 architecture (as has been announced for June 2006). Offers some degree of Linux and BSD compatibility, and has a limited but successful position in the gaming market.

Figure 36 - Hexley, the Darwin Mascot.

Note that a custom OS is not listed as a possibility - implementing an OS from scratch is a more taxing task than many Computer Engineers will ever face, and simply not a practical option.

Also note that there are numerous other operating systems that will physically run on a typical x86-compatible system, but they are either wholly inappropriate for a games console (e.g. VxWorks) or do not have a sufficient number and level of games available for them (e.g. BeOS, RISC OS, Haiku, etc).

Given these options, Windows and Linux are clearly ahead of the other candidates. The BSDs are similar to but offer no clear advantage over Linux. And given that the vast majority of embedded systems are based around x86-compatible processors, MacOS X falls out by default.

Choosing between Windows and Linux is more difficult. Windows is not free, but it is trivial to install and configure. Linux may be free as in beer, but it takes significant knowledge to setup and configure. For a custom-purpose system such as a games console, it requires even more expertise than normal. Additionally, many of the most popular games are not available for Linux, even when using Windows compatibility layers such as Wine.

Given this conflict, it seemed appropriate to test both systems on the prototype. Two similar hard drives were used to this end, one for each OS. It is possible for a dual-OS approach like this to be adopted more generally, but it is generally unwise - consumers will not understand why the two are necessary, and will not appreciate the extra complexity and confusion.

2.1.9 Conclusion

A home games console certainly seems at least attemptable, given current technology and economics. It is unlikely it will be truly competitive with existing consoles - especially given the imminent release of the next generation of consoles - but it will certainly be a useful learning exercise for others who might make further attempts in future.

3.0 Assembly

This section looks at how the prototype console has assembled. In particular, it details the problems encountered, solutions or workarounds adopted, and notes the numerous avenues for future work.

3.1 HARDWARE

To get things started off, the items listed below were ordered from On Line Marketing (Australia) [27]. All prices include GST.

- VIA EPIA-SP8000E Mini ITX Mainboard with 800MHz Fanless processor ($300.63AU)
- Powerhouse KY-600ATX 20 or /24 PIN exchangeable 500W ATX PSU ($21.51AU)
- Kingston KHX3200A/256 HyperX DDR 256MB 400MHz DDR Non-ECC CL2 (2-3-2-6-1) DIMM ($69.81AU)
- Logitech Wingman Precious USB Gamepad - 6 buttons, 8-way D-pad ($14.91AU)

Keep in mind that for the purposes of this thesis it can be assumed any fanless VIA EPIA board can be used, and so the minimum mainboard cost is actually $160AU (for the EPIA ESP5000).

In addition, the author managed to salvage the following items from his spare parts bin and from friends:

- 24x Sony IDE CD-ROM
- 24x Acer IDE CD-ROM
- 200W generic PSU
- Fujitsu 3.2 GB IDE hard disk
- Western Digital 3.2 GB IDE hard disk

- 2 x dual-header IDE cables
- 2 x dual-socket USB PCI headers
- 64 MiB USB flash memory stick

Additionally, during the course of construction the following additional items were purchased:

- OfficeWorks PS/2 keyboard, USB mouse and twin speakers bundle ($29.95AU)

Of course, ideally a keyboard and mouse would not be necessary, and audio is provided via the TV output. Unfortunately, a common theme throughout this section is the need for a keyboard and/or mouse.

3.1.1 Initial Assembly

The first stage was to put the basic components together and ensure they worked. The PSU connected to the mainboard using a standard 20-pin ATX connector. The two hard drives and CD-ROM drives were alternately connected to verify that they worked.

The mainboard did not come with many of the usually standard extras - such as USB sockets for the onboard headers, audio cables for connecting CD-ROMs to the onboard audio inputs, etc. It did not even come with feet to support itself. A trip to Dick Smith Electronics and a few dollars later, and some suitable plastic feet were soon attached to the mainboard, giving it plenty of ground clearance.

The next problem was that, while the PSU has it's own master power switch, the mainboard does not turn on until it's own power button is pressed. Unfortunately, this power button is not included - just a standard front panel 15-pin header. Without a PC case to provide the appropriate connectivity, a temporary workaround was found - taking any metal object (e.g. a DMM probe, or a piece of wire) and shorting pins 5 and 7 of the header.

At this point it would be expected that the system would turn on, find the hard drive or CD-ROM drive connected to it, and boot from either one appropriately. Unfortunately, it instead issues a warning on the BIOS boot screen, indicating that the system configuration had changed. Press F1 to continue. So apparently it is impossible to boot

VIAs MiniITX boards without a keyboard, for the first boot at least. This was a most unexpected hiccup. While it's reasonable to expect the average person to have a keyboard in their household, which they could temporarily use to get past this hold up, it is an annoyance - and certainly not good enough for the console to be sold commercially.

Once F1 was hit - neither a mouse button nor gamepad button press was sufficient - the system did boot for the first time. The salvaged hard drives both contained copies of Windows 98, which booted up without significant issue. Both went through a long period of detecting new hardware and installing drivers, but eventually were up and running properly. Unfortunately, without USB support - it appears for whatever reason Windows 98 is not compatible with the USB hardware on the MiniITX system (with it's default drivers, at least).

Nonetheless, now that the system was proven, construction of the case could begin.

3.1.2 Breaking open the case

The VCR case used initially contained a fully working VCR, which had to be removed first, of course. This was reasonably straight-forward - a Phillips-head screwdriver was all that was required, along with some good old fashioned heavy handedness, to remove the internal components.

The VCR mainboard and other internals were mounted on various supports and sockets moulded into the case itself. These were not arranged in a way that was amenable to our intended use, and so had to be removed. The casing is a fairly malleable plastic, and so it was eventually found that a pair of solid pliers were the best method for removing unwanted parts of the case. Unfortunately, the finish resulting from this brute-force approach was not very nice - the twisted and torn plastic was quite sharp and still obtrusive. A file was used to remove the worst of these. This process took quite some time.

There was some luck with the VCRs layout that worked in favour of the console. The back panel of the VCR already had a slot in it where the back of the mainboard - with it's various connectors - could be exposed. This area of the case did not strictly require any machining. However, the PS/2 ports were not accessible, as the rear opening did not extend quite far enough. As was later discovered, it really isn't possible to use this prototype system without at least sometimes attaching a keyboard and mouse. Given a USB keyboard was not available, the PS/2 ports had to be made available. Thus, the back opening was expanded slightly. This did, however, reduce the structural integrity of the case. Not significantly enough to be a pressing concern, but to be noted as one of the reasons why a purpose-built case is more ideal.

Aside from this unfortunate minor issue, the mainboard fitted quite snugly into the corner of the case, with the four attached feet finding almost perfect positions within the moulding. They were later attached via screws to the bottom of the case for extra stability.

The PSU, however, presented something more of a problem. The actual unit is approximately the same height as the case. The top of the case is metal and can bend a little, so this is not strictly a problem. However, it was crucial that the PSU be as flush to the bottom of the case as possible. This was easier said than done - with just a hack saw, a file, a pair of pliers and a pair of wire cutters, it is no easy task to try to remove bumps within the case. After several hours, little progress had been made on some of the worst obstructions. After acquiring an electric drill, courtesy of Robert Ross, these final obstructions were quickly dispatched. With them gone, and with an hour or two of persistent filing, the PSU sat flush against the bottom of the case.

A hacksaw and the pliers were used to carve out an opening (in the back of the case) for the PSUs power cable and for access to it's power switch. While the case did have a hole in the same area for it's own PSU originally, it used a small figure-eight power cable, not a generic PC power cable. In any case, the PSU sockets were not in the same position, so adjustments were inevitable.

An electric drill was used to create a coarse mesh on the back of the case, to ensure the PSU had sufficient air flow. Additionally, screw holes were added to allow at least one side of the PSU to be screwed to the case.

Which introduces one of the biggest problems with the case - the lack of facilities for securing the components. The mainboard requires four screws into it's feet to be secured, which ultimately required holes to be drilled in the bottom of the case. The PSU was only partially secured by the two screws into the case - any substantial sideways force could pivot it around these screws. And additional devices such as hard drives and the extra USB connectors also had nothing to be attached to.

At time of writing, a satisfactory method for securing the hard drive(s) has still not been found, and they sit relatively loosely inside the case.

3.2 Software

As was discussed in the design section, the choice of OS was narrowed down to Windows or Linux. Which is to say, it's still very much wide open. Unfortunately the nature of software is such that all good designs and intentions tend to get left to the wind, so the process ultimately fell upon trial and error. This section is particular important, as it highlights the real show-stoppers for a home console.

Since the Open Games Console is being approached as a DIY-style project, the end user should be able to install the chosen OS without undue difficulty. This, as will be shown, definitely acts as a deterrent to the use of Linux.

3.2.1 Running a GamesKnoppix (Linux) LiveCD

A LiveCD is a CD (or DVD) containing an entire OS (e.g. Linux) designed to boot directly from the CD, without requiring any writable media (e.g. a hard drive) to be installed. Most LiveCDs are designed to allow people to test-drive a given OS, or for people who would like to dabble in an alternative OS - such as Linux - without modifying their existing system.

The representative LiveCD tried on the prototype system was GamesKnoppix. This is a special version of the Knoppix LiveCD Linux distribution which ships with over a hundred open source games on the CD.

It takes approximately two minutes to boot GamesKnoppix on the prototype system, which is clearly too long for regular use. It did automatically detect the PS/2 keyboard and USB mouse plugged into it, but did not immediately make use of the USB gamepad. This poses quite a problem - the final console would not necessarily have a keyboard or mouse available. Unfortunately, without at least one or the other, GamesKnoppix is not usable.

Additionally, GamesKnoppix is unable to read FAT32 formatted devices, such as Windows hard drives or USB storage devices. This poses a significant problem, as the vast majority of USB Flash memory sticks are FAT32 formatted.

Once a game - e.g. SuperTux - was launched via the keyboard or mouse, the gamepad could be used for the most part. Unfortunately, the gamepad appears as a keyboard to the game, but mapped only to a limited number of keys - e.g. the arrow keys. When it comes to others (such as the control, alt or shift keys), there is no apparent way to map the gamepad buttons into the game. In SuperTux, for example, this creates quite a problem, as by default none of the gamepad keys were mapped to the Run key. This makes it impossible to even finish the first level.

And while an experienced user can fiddle with settings in the KDE Control Panel, there is no way to modify actual key mappings there. Additionally, many changes require KDE to restart, which takes approximately a minute to do.

The problem persists with numerous other games. For example, XGalaga works fine with a gamepad - provided you have a keyboard plugged in so you can press "k" to select the gamepad. Additionally, XGalaga (and many other Linux games) do not go into full screen mode by default; some do not even support it.

Other problems include the system locking up sometimes when leaving full screen mode, and other stability issues.

It should be noted that there are numerous programs available for Linux designed specifically to provide full system control using a gamepad or joystick. Some simply re-map the gamepad inputs to take control of the mouse, or to user-configurable keys. Others go as far as providing a virtual keyboard on screen, which you can navigate and type from using the gamepad. Unfortunately, GamesKnoppix does not include any of these.

Evidently GamesKnoppix is not suitable for a games console. It is unlikely that any other existing LiveCDs will fare much better, given the very specific requirements the prototype has. Significant customisation is required - and can be done, for a version of Linux installed on a hard drive or similar. But not with a LiveCD.

3.2.2 Running Linux from a USB Flash memory device

There are many Linux distributions which fit onto even the smallest USB devices - 64 MiB or less. Additionally, many distributions offer so-called "business card" installers, which are designed to be as small as possible. They do not provide a working Linux system straight off, but rather can be used to install Linux onto a hard disk or other storage device, using a network connection or other source to acquire the necessary packages.

Thus, a business card installer of Debian 3.1r0 (Sarge) was loaded onto a 64 MiB memory stick, and an attempt made to boot the prototype with it. It is known that VIAs EPIA boards can boot from at least some USB storage devices. Unfortunately, the specific one used is apparently not one of them.

This is a common problem with USB storage devices - particularly cheap memory sticks - which all misinterpret the supposed standards in new and interesting ways.

Of course, another memory stick could be tried, however the author did not have one available at the time.

3.2.3 Installing Gentoo Linux 2005.1 from CD

Gentoo is the Linux distribution of choice for those who like to tweak their system's to achieve absolutely peak performance. It's standard installation procedure builds the entire OS and all it's bundled utilities from source. After spending several hours tweaking the compiler parameters to ensure they're optimal.

On one hand, performance is critical on a resource-limited machine like the prototype, so an OS that is built specifically for it is ideal. However, the process is far from trivial, and while the Gentoo Handbook [26] does walk through it reasonably well, the user does need at least some Linux knowledge and experience.

Thus, Gentoo is a good choice from which to build a master image for the Open Games Console, which could be done by a knowledgeable person or company, and then a click-through installation CD provided to end users.

For experimental purposes, a significant effort was made to install Gentoo nonetheless. This ultimately failed, with various critical stages of the installation reporting meaningless errors that could not be resolved. Like most Linux distributions, Gentoo is not for the faint hearted, or those who like their OS installs to take less than a week.

Additionally, it was later discovered that Gentoo had corrupted the MBR (Master Boot Record) of the drive it was trying to be installed on, which certainly bodes very poorly for future work with it.

3.2.4 Installing Windows XP Professional from CD

In contrast to Linux, Windows is trivial to install. While the first CD used was corrupt and would not install, a second attempt saw Windows install itself flawlessly, albeit slowly (taking several hours).

Once installed, the next step was to install VIAs drivers. Without proper display drivers, Direct3D could not use the hardware accelerated 3D. Without the sound drivers, no sound was available. And so on. Window's default driver database clearly does not cover this area of the market. Unfortunately, VIA don't make it easy to get the necessary drivers installed - they provide at least two separate places from which to obtain drivers, without a single location that contains all of them.

Additionally, they mix their generic chipset drivers up with those specific to the EPIA range, creating further confusion both to the user and to Windows.

Beyond these installation issues, there are similar problems as experienced with the GamesKnoppix Linux OS - i.e. the OS is fundamentally dependent on a keyboard and mouse, and cannot be installed or used without one.

Luckily there are several programs, as with Linux, for using a gamepad or joystick as a substitute for the keyboard and mouse. Unfortunately the author did not have time to test these.

4.0 Conclusion

A lot was learnt from this thesis, despite the somewhat mediocre outcome. For better or worse, much of it was what not to do. There's certainly a lot of work to be done by a great many people before the Open Games Console reaches it's potential. This summary and conclusion will look at what works, what does not, and what can be investigated in future work.

4.1 What went Right

Choosing to attempt a prototype of a home console, rather than a portable console, was an excellent choice for practical reasons. While the author has worked on major embedded Linux systems before, he cannot conjure one up in mere moments - indeed, that experience has shown him just how much is required to build an embedded system.

The decision to recycle a VCR case instead of purchasing a real MiniITX case was both economically and practical advantageous - it shaved a significant amount off the cost of the system, while still presenting a clean, pleasant appearance at the end. Albeit perhaps a little confusing, given it's clear VCR appearance.

While it was originally assumed Linux would be the OS of choice, planning ahead and evaluating several options turned out to be very wise indeed, given even after several attempts Linux was not installed onto the prototype system. Having Windows available as an alternate OS saved the prototype from ending up completely inert.

The choice of MiniITX board was an excellent one in terms of functionality - it provides the majority of the functions available from VIA EPIA mainboards, making it a good sample system for evaluating the strengths and weaknesses of each individual feature.

4.2 What Went Wrong

Too much time was spent aiming for a portable console - several months, in fact. It seemed it could be achievable at various times, which led on and on… ultimately losses should have been cut much earlier, and more immediate returns achieved via the home console approach.

Also, the software side of the prototype should have been explored much earlier, even if the hardware and casing were still being assembled. Leaving this aspect so late into the project meant that when the problems arose with Linux there was insufficient time to properly pursue alternatives (i.e. Windows).

While the EPIA SP8000E was a good choice in terms of functionality, the fanless nature of the mainboard was made irrelevant by the other components - including a noisy PSU, hard drives and CD-ROM drives. In future, it may be best to just accept a small fan on the mainboard, in order to gain access to the higher performance mainboards - such as those using Pentium M processors, which completely outclass the VIA Eden processor. Future work might wish to look instead at noise absorption or deflection in the case, as an alternative way to achieve a quiet system.

In contrast to the suitability of the mainboard as a representative of the whole range, the choice of gamepad was very poor. Far more functional gamepads are not significantly more expensive, and would have been far more valuable as prototyping tools. In particular, a gamepad with at least one joystick built-in would have been advantageous.

More weight should have been put on the PSU, in terms of budgeting. A good $80AU slim PSU would be quieter and smaller, leaving more room in the case for other components, and allowing the use of smaller cases.

4.3 Future Work

There are a few things really need to be changed dramatically before the Open Games Console becomes a reality, and many things that could be significantly improved.

4.3.1 Critical

First and foremost, OS's need to be adapted to better suit gaming conditions - i.e. where there is no mouse or keyboard, and may never be. While it is always possible with Windows and Linux to install 3rd party programs to end this end, this can only be done once the OS is installed - which of course requires a mouse & keyboard to do so. This would be a very good aim for an Open Games Linux distribution, which could come pre-packaged as a LiveCD that can be used and installed using *any* controller - whether a keyboard, mouse, gamepad or other similar device.

Next most important is a change in the default configuration on VIAs EPIA mainboards. As mentioned, these mainboards by default cannot be booted after a hardware configuration change without a keyboard. This problematic warning can be disabled in the BIOS, but again, only with a keyboard. If the default behaviour were changed by VIA to issue no warning, the system could boot directly first time. This is not a project that could be undertaken academically - VIA need to update their boards. Alternatively, mainboards from other manufacturers could be investigated to see if they avoid this problem.

With regards to LCD panels, this is again one of the critical impediments to a portable console. While an academic cannot do much to change the existing market, short of revolutionising LCD manufacture, alternative avenues could include research into how to salvage high quality LCDs from PDAs, PSPs or other such devices. This was mentioned but not investigated in this thesis due to the substantial costs involved in acquiring such devices for experimentation.

Also, like LCD panels, slim-line DVD-ROM drives are very expensive, making them prohibitive to use in a games console. Until they become significantly cheaper, alternatives such as USB memory sticks will be far more attractive.

4.3.2 Desirable

While not wishing to condone copyright infringement, the need to have the original game CD/DVD in the system to run certain games is a problem. It makes it very difficult for a portable devices, which won't have a CD/DVD drive, and similarly for home consoles which wish to explore other methods of managing software. At present the solution is to obtain cracks for such games from certain shady websites, but this is clearly not a sustainable solution, nor necessarily a legal one. Future work could look at alternative ways to provide this physical media copy protection, without directly and completely circumventing the established methods.

Additionally, a software application to provide a simple interface to the console would be an excellent idea. Such an interface would be attractive but simple - providing easy access to the core functionality, such as loading games, playing DVDs or music, copying data to and from various storage devices, etc. There do exist some 3rd party applications designed for this purpose, which while not evaluated thoroughly in this thesis were seen at a glance to be quite lacking.

4.3.3 Additional

Other possible areas of related work include looking at a variety of input methods for consoles. Things such as traditional control devices - buttons, joysticks, scroll wheels or strips, etc - as well as less conventional methods, such as audio cues, motion (using accelerometers or gyroscopes), etc. In particular, a focus on portable consoles could produce some quite innovative new approaches to portable entertainment.

Lastly, it would be interesting to evaluate how well various touchscreen LCD panels integrate with existing systems, such as Linux and Windows. The use of a touchscreen on a portable console has clear advantages in terms of usability and the range of games which can be played on the console (Nintendo's DS being the case in point).

4.4 Final Thoughts

The time of the Open Games Console is coming, probably sooner than many of the commercial players imagine, and certainly much faster than they'd like. Already there is niche competition, such as the GP2X from Gamepark, and there is clearly strong interest in the areas of home entertainment and "Media Centre" PCs from the PC hacking crowd. Modern MiniITX mainboards are nearly matching the performance of high-range PCs in a range of areas. Recent models include PCI Express, which allows the use of high-end graphics cards. Use of these will further narrow the gap.

Ultimately, however, there are still substantial economic and technical problems to be overcome, as this thesis has shown. It is the authors opinion, optimistically, that this is not a matter of if but of when.

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6.0 Glossary

802.11 - The predominant technology used for wireless networking. Also known as Airport.

Arcade - A public place which operates some number of Arcade Machines (among other services), which provide interactive entertainment typically on a pay-per-play basis.

Arcade Machine - A computer gaming device design to operate in public venues, typically in Arcades. The device is characterised by a large purpose-built case with built-in screen and robust controls. Typically requires user to pay per play.

ATA - Advanced Technology Attachment. A method for connecting block devices (primarily hard drives) to a computer system. Widely adopted as the standard method for many years. Comes in many speeds and variations - typically suffixed with a number indicating the peak transfer rate in megabytes per second, e.g. ATA/133 indicates an ATA interface that supports a transfer rate of up to 133 megabytes per second.

Baseboard - A supporting PCB which provides interconnection between numerous daughterboards. Distinct from a mainboard in that it does not serve any purpose beyond linking the daughterboards.

Bluetooth - A wireless networking technology designed for short-range, low-power applications. Typically used to connect mobile phones to other devices, and for wireless keyboards and mice for PCs.

CD - Compact Disc. A (typically) circular disc used to store up to 700 megabytes of information.

Console - Used interchangeably with "Game Console" throughout this document. See Game Console.

CPU - Central Processing Unit. The electronic chip inside a computing device which controls all the other chips and devices within the computing system. Typically the CPU runs most or all the software that instructs the computer on how to operate.

CRT - Cathode Ray Tube. Colloquially used to refer to display devices that use CRTs, which are characterised by their significant depth, making them completely unsuitable for portable devices.

Daughterboard - A PCB which connects with and serves a mainboard or baseboard. Typically they provide specific additional functionality, such as graphics acceleration, networking or other focused area.

DDR - In the context of SDRAM, Double Data Rate. Refers to SDRAM which transfers data on both the rising and falling edge of the clock, giving it twice the effective clock rate as older SDR SDRAM.

DRAM - Dynamic Random Access Memory. The dominant type of volatile memory used in today's PCs. Not to be confused with SRAM, which holds it's stored value indefinitely (while power is maintained), in contrast to DRAM which must be periodically refreshed in order to maintain stored values.

DVD - Digital Versatile Disc. A successor to the CD with very similar physical dimensions and appearance, but capable of storing up to 9 gigabytes of information.

Ethernet - A very common networking scheme. In this document Ethernet describes wired networking - the connection of two or more devices via a cable which allows them to interact using predefined protocols.

ETX - A standard for systems based around a baseboard into which numerous modules - e.g. CPU boards, interface boards, etc - can be slotted. The standard covers the mechanical and electrical characteristics of the connections involved. It was originally defined by JUMPtec, now owned by Kontron.

Flash (memory) - A type of solid-state (non-volatile) programmable memory, typically used for storing medium to long term data such as device firmware or user data (e.g. photos, music, saved games, etc).

Firewire - Apple Computer's brand name for IEEE1394, a connection method for high speed communication between two or more devices. Typically used for external storage devices (hard drives, CD/DVD drives, etc) and video cameras. Also used for networking as a substitute for Ethernet cabling.

Firmware - A specific type of software which instructs the hardware how to configure itself when activated, and serves as an abstraction of the hardware to the software, to simply programming of the device.

Game Console - A computing device traditionally associated with gaming, which comprises either a central unit with associated controllers and outputs (typically to a TV), or in portable consoles the entire unit with built-in display, controls, etc.

GPU - Graphics Processing Unit. An electronic chip (typically) similar in size to a CPU, but designed specifically for performing graphical tasks, such as 2D & 3D rendering.

Headers - In the context of mainboards or similar, refers to rows of pin connectors on the board. Typical PC mainboards, for example, provide several USB headers, in addition to any onboard USB connectors. Additional USB ports can be connected via the standard headers.

LCD - Liquid Crystal Display. A display technology that is rapidly replacing CRTs by virtue of it's improved power efficiency, clarity and hugely reduced size (particularly depth).

Mainboard - The dominant PCB in a PC-like computer architecture, containing the CPU(s) and core circuitry (which may include integrated peripherals such as Ethernet controllers, graphics accelerators, etc).

Motherboard - The traditional name for mainboards, deemed politically incorrect.

OS - Operating System. The software that (typically) is loaded first on a computing device, and manages subsequent loading of games or other such software. Often also provides libraries and interfaces that help other software run.

NES - Nintendo Entertainment System. A video game system released in 1985 by Nintendo, which was pivotal in popularising the home console.

PATA - The new "politically correct" name for what was previously called just ATA. Used now to more clearly differentiate between older parallel ATA and the newer SATA standard.

PC - Personal Computer, a general purpose computing device in common use. Typically much larger than a console and designed for multiple simultaneous functions.

PCB - Printed Circuit Board. A board - typically solid and made of a combination of materials such as fibreglass, plastic, hard resins and metals - upon which electrical components and circuitry is placed.

PC/104 - An embedded computer standard (defined by the PC/104 Consortium), which encompassed an inter-board bus and standard form factor (90.17 x 95.89mm). The primary distinction of the boards relative to normal embedded systems is that they are designed to connect together, but without a backplane common in most designs - boards are daisy-chained via the ISA-like bus. Commonly used in industrial control applications.

PC/104+ - An extension of the PC/104 standard that incorporates PCI in addition to ISA in the interface between board.

PCI/104 - A revision of the PC/104+ standard which drops ISA. Not widely used.

PIM - Personal Information Management. A recent buzzword used to describe management of personal information - things like a person's address book, calendar, correspondence, etc.

Platform - A particular combination of hardware and software, defined by it's compatibility (or lack there of) between other hardware and/or software. For example, an PC running Windows may be referred to as a "Windows" platform. More generally, a PC running any OS may be referred to as a "PC" platform (as opposed to an Xbox platform, for example).

Platformer - A particular genre of game in which a character navigates a 2D world from a side-on perspective. The dominant playing characteristics are interaction between adversaries and navigation of difficult terrain, composed of numerous separate platforms - ergo the name.

PS - PlayStation, the first home console released by Sony.

PS one - A smaller version of the original PlayStation released some years after the first. Aside from the reduction in size, there were no major functional changes.

PS2 - PlayStation 2, the second generation of home console released by Sony.

PS3 - PlayStation 3, the third generation of home console from Sony, yet to be released at time of writing, but expect in the second quarter of 2006.

PSP - PlayStation Portable, a particular model of portable game console released by Sony.

QDR - In the context of RAM, Quad Data Rate. Refers to memory which transfers data four times per clock, providing an effective clock four times higher than normal. Rare in today's PCs.

Saved Game - Data stored on a non-volatile medium which records the state of game-play at a particular point, allowing this state to be restored at a latter time and thus allowing the player to resume their game.

RAM - Random Access Memory. Memory that can be read and written symmetrically, usually with no limit on the number of each. Typically the term RAM implies volatile memory.

ROM - Read Only Memory. Typically a kind of write-once electronic device, which usually contains the firmware and sometimes the OS for a given device. Older consoles used ROM in the place of CDs on newer consoles, to hold games and other software console content.

SATA - Serial ATA. A modern adaptation of the venerable ATA standard for block devices (typically hard drives), boasting larger bandwidth and additional features that improve performance of very fast devices. Currently has a relatively small installed base, but is found on the majority of modern mainboards.

SDR - In the context of RAM, Single Data Rate. Refers to RAM which transfers data on only one edge of the clock, whether rising or falling. Made obsolete by DDR & QDR.

SDRAM - Synchronous DRAM. The dominant type of volatile memory used in today's PCs.

SMS - Sega Master System. A home games console released by Sega to compete with the NES. Technically superior, but less popular.

SRAM - Static Random Access Memory. A type of memory used primarily for very high-speed applications in today's PCs (e.g. CPU caches), where data in memory is stored indefinitely (provided power is maintained).

TV - Television. A display device originally for watching audio-visual broadcast content, but with provision for other inputs, such as from a game console.

UMD - Universal Media Disc. A proprietary disc medium developed by Sony specifically for use with their PSP.

USB - Universal Serial Bus. A very common connection scheme for computing devices, particularly peripherals such as input devices and still cameras.

UWB - Ultra Wideband. An upcoming communication technology which avoids licensing issues by broadcasting at extremely low power, and is consequently difficult to detect and robust against interference.

VR - Virtual Reality. Idealistically the ability to present a virtual world to a player that is as realistic as the real world. Typically used to describe any technology or game which endeavours towards this goal.