Chapter 5: RAM

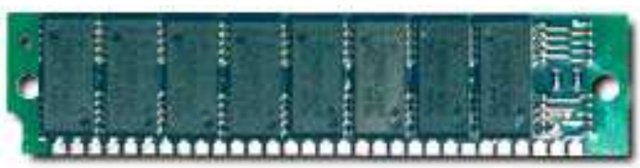
What is RAM?

The term 'RAM' is an acronym for Random Access Memory, this is the memory that your computer uses to run its operating system and any applications that you start. The name means that the computer can access information held anywhere (i.e. at a random location) in RAM by addressing that part of the RAM directly. In other words if there is some information stored in the 1000th location in memory the system does not have to read the information in the preceding 999 locations to get there, instead it can access the 1000th location simply by specifying it. The alternative would be called sequential access, an example of which would be accessing information stored on a hard drive - the drive can only read the information which is currently passing underneath the read/write heads, so if an application wants information in say sector 14 of a certain track the drive has no option but to read all the information on that track. The drive electronics then separates out the information from sector 14 and returns that to the application, the information from the rest of the track is discarded. So RAM is the quickest way of organizing information for retrieval. Why not have everything on your computer stored on RAM? The answer is cost and volatility - RAM costs far more per GB than a hard drive and most RAM requires power to maintain the information stored in it (It's memory is "volatile"). If you had a RAM only computer you would have to reload the operating system and all your applications and data every time you switched off or there was a power cut. There are appropriate uses for this type of computer (e.g. thin clients) but generally a system is best served by a mix of RAM and Drive storage. Your computer needs different amounts of RAM for different tasks and the more applications you open the more RAM is required. You might think that sooner or later you will run out of RAM and then what? Well the operating system is designed to cope with that situation by 'paging' blocks of RAM to the Hard Drive. What that means is if the system is running out of RAM it takes the contents of a 'chunk' of RAM (usually the least used part) and writes it to a reserved area of the Hard Drive, called the Page File or Swap Space. The 'chunk' of RAM is then declared free for use. **By using the swap space in this way the system normally never runs out of RAM.** But as we have already discussed accessing information on the Hard Drive is inherently slower than accessing it from RAM so the result is the computer slows down. No one likes a slow computer so what do you do about it? Obviously you want to add more RAM but to do this you need to match the additional RAM with what is already in your PC and you need to be sure your motherboard will support the kind of RAM you intend to use.

Different Types of Memory & Some Terminology

In "the beginning" RAM came in the form of semiconductor chips which were individually plugged, or soldered, into the motherboard. That made up the original 640KB of system memory that DOS hung onto for so long. Now memory comes in clip-in modules, usually called memory sticks (not to be confused with USB Flash drives which sometimes go by that name). Memory sticks or modules have changed format over the years as their capacity has increased. Here is a list of the main types, in rough order of increasing complexity, along with other terms used to describe them:

A 30pin SIP module



A 30pin SIMM module

A DIMM module *

A DDR module with heatspreaders *

A DDR2 module with large heatspreaders *

- Pins - Originally the name for the "legs" on a memory module, similar to the legs (or lead) on an electronic chip. The terminology has carried over to describe the number of contacts on memory modules even when they are not pins.
- Bus - A group of electrical conductors linking different parts of the computer. Just as a bus in real life is a means of transporting large numbers of people from one location to another, so a bus in a computer is a means of transporting large numbers of signals (or data) from one integrated circuit to another. For example the front-side bus (FSB) transports data between the CPU and the Memory Controller (and to other destinations). Buses may contain subgroups that are also buses, for example the "Memory Bus" which links the Memory Controller and the RAM contains an address bus, a data bus and a command bus.
- SIP - Single Inline Package - an obsolete type of memory module with a single row of (actual) pins along one side.
- SIMM - Single Inline Memory Module - an obsolete type of memory stick with power and data contacts on one side of the board. 30 pins.
- DRAM - Dynamic Random Access Memory - a generic term describing RAM in which the data needs to be refreshed continually. Very widely used in mass production PCs.
- SRAM - Static Random Access Memory - a generic term describing RAM in which the data is retained without the need to refresh. Faster, larger and more expensive than DRAM.
- Cache Memory - Cache is a term used to describe a number of different functions in the computer. Cache memory is a separate store of SRAM used by the CPU to store the most frequently used 'information'. The cache can be accessed more quickly than normal RAM so by storing frequently used functions/data there an overall speed increase can be obtained. There are different "levels" of cache depending on how close they are to the CPU, Level 1 cache is actually part of the CPU chip itself, Level 2 and Level 3 are external to the CPU usually on the motherboard.

- FP - Fast Page RAM - A type of DRAM, introduced in 1987, which allows multiple accesses to a memory location without the need to re-specify the address.
- EDO - Extended Data Output RAM - a type of DRAM which uses assumptions about the next memory access to pre-read data. Introduced in 1990 with approx 10% increase in speed over Fast Page. Sometimes known as Hyper Page Mode (HPM).
- DIMM - Dual Inline Memory Module - a memory stick with power and data contacts on both sides of the board.
- Parity - Parity is part of an error checking process that can be used to verify the integrity of data stored in RAM. The data is stored, as is always the case in computers, in binary - a sequence of eight ones and zeroes which make up the byte of data. The Parity of that data byte is found by determining whether there are an odd number or even number of ones in the data. The parity of each data byte can then be stored by adding an additional bit of data, which can be either a one or a zero. This extra bit of data is called the 'Parity Bit'. In the 'even parity' system if the total number of ones in the byte is an odd number the parity bit is set to one, thus evening up the number of ones. (There is also an 'odd parity' system which is the other way round just to confuse us all). When the data is read back into the system the computer again calculates the parity of the data byte and compares that to the parity bit that was stored with it. If the calculated and stored parities agree then all is well (usually) but if they disagree then there has been an error and the data byte is suspect. To use parity error checking the RAM must be able to store nine bits per byte of information.
- ECC - Error Correcting Code - RAM that has additional data storage for checksum bits to allow **correction** of errors 'on the fly'. The memory controller on the motherboard must support this function.
- SDRAM - Single data-rate Synchronous Dynamic Random Access Memory - Introduced in 1997, memory access is synchronised to the bus clock and the bus is 64 bits wide. 168 pin modules.
- RAMBUS - A revolutionary memory technology developed by Rambus Inc. based on a type of video memory and designed for use in PCs with Intel processors. Introduced in 1999.
- RIMM - Rambus Inline Memory Module - the memory stick used in systems using Rambus RAM. 184 pin modules.

- C-RIMM - The continuity module required to fill empty memory slots in the Rambus system.
- RDRAM - Rambus DRAM - originally designed to operate at bus speeds of up to 800MHz but only 16bits in width.

- DDR - Double Data Rate memory - a type of DRAM based on SDRAM technology that operates at twice the bus clock rate. It uses 184 pin modules. Released in 2000. This was the mainstream memory technology to the end of 2005.
- SODIMM and SORIMM - Small Outline versions of DIMM and RIMM sticks. These are smaller and thinner memory modules, typically used in laptops. Modules have 144 or 200 pins.
- SPD - Serial Presence Detect - circuitry (an EEPROM) built in to a RAM module which will send information to the BIOS and to the Memory Controller to inform it what type and how much memory is present, where it is and set up complex timing parameters.
- Heat Spreader - A thin metal cover making thermal contact with the memory chips and assisting in cooling. Also allows manufacturers to put large logos and badges on the memory modules.
- DDR2 - Double Data Rate2 memory - a type of DRAM based on DDR technology that operates at twice the clock rate. Released in 2004. This is expected to be the mainstream memory technology to the end of 2007. Not compatible with DDR motherboards. Modules have 240 pins.
- Dual Channel Memory - There is no difference between Dual Channel DDR Memory and ordinary DDR Memory, it's the motherboard that is different. Systems that have dual channel capabilities can effectively double the bandwidth of the Memory Bus by accessing the RAM modules in pairs. To use Dual Channelling you would purchase RAM in matched pairs and install it symmetrically across the memory channels.
- Virtual Memory - This is RAM that is simulated by the system when running out of space in the real memory modules, it is actually space on the Hard Drive and as such is far slower to access than real RAM. Significant degradation of system performance occurs if more than a certain percentage of current data resides in virtual memory.
- Latency - A delay interval. I was hoping to gloss over this but so many RAM companies quote latency figures it's bound to come up. See the section on Latency below.

- Bank - A group of memory chips (not modules) that together can supply enough data bits to equal the CPU data bus. In the days of 30 pin modules memory chips only held one bit per address and you could only fit 8 chips on a module so to "fill" the 486CPU's data bus (which was 32 bits wide), you needed **four modules** to make one bank. The introduction of 72 pin SIMMs meant the whole 32bits of data could be supplied by one module, but when the Pentium CPU was introduced with a 64bit data bus so you needed 2 SIMMs to make a bank. This explains why owners of older Pentium systems always had to add or upgrade their memory in *pairs*. With the introduction of the 168pin DIMM this drawback was overcome and now there can be many banks of RAM on one memory module.

- Rank - row of memory chips. Usually a rank fills one side of a memory module so if your module has two ranks that means there are chips on both sides.

Common RAM Sizes

If I remember correctly the original SIMMs came in 256KB, 512KB and 1MB packages and cost a small fortune. In the days of Windows 95 a computer would commonly have several 4MB or 8MB memory modules. By the time Windows 98 came out these had become 16MB or 32MB modules to make up around 64MB in a good system. For Windows XP computers 128MB is a workable minimum depending on what applications you want to run, modules tend to be 128MB, 256MB or 512MB. Currently systems routinely ship with 512MB sticks and 1GB sticks are becoming more common.

RAM module sizes always double: 4MB, 8MB, 16MB, 32MB, 64MB, 128MB, 256MB, 512MB, 1GB, 2GB, etc. (since strictly speaking 1GB = 1024MB) You wont find any 96MB RAM modules for example, but your system may have an "unusual" amount of total RAM for a couple of reasons

- The system contains different sized RAM modules.
- For example your system shows 192MB of RAM. Most likely this was a system that started life with 64MB of SDRAM and was upgraded by adding a 128MB module.
- The system has onboard video.
- When a system has onboard video the video 'card' is integrated into the motherboard, but no video memory is provided, instead the system reserves part of the system RAM to act as video memory. How much memory is reserved depends on settings in the BIOS and is usually any standard size from 4MB to 64MB. The 'total' amount of RAM that Windows sees is then the size of the RAM module, less the amount reserved for video. This can result in some very odd-looking amounts for total system RAM. For example a system's total RAM may be reported as 352MB. This could be made up of one 128MB module plus one 256MB module less 32MB reserved for video.

RAM Speed

The RAM in Intel based computers is accessed by the CPU via the front-side bus (FSB) and the memory bus. Improvements in technology have changed the speed of the FSB dramatically. Similarly the RAM itself has a maximum speed at which it can reliably operate and this must be at least as high as the memory bus speed. Clearly there is a 'grey area' where the definition of reliable operation is made and this is one difference between 'low quality' and 'high quality' RAM - the high quality RAM is likely to operate with close to 100% reliability significantly above the bus speed for which it is rated. This is one of the regions that over-clockers exploit to boost their system performance - increasing the FSB speed to take advantage of the performance 'buffer zone' of good quality RAM.

Obsolete SIMM modules (EDO or FP) were rated by the response of the chips on the module e.g. 70 nanosecond. Older SDRAM sticks were rated as 66MHz, 100MHz (PC100) or 133MHz (PC133) speeds. Original DDR was rated at PC1600 or PC2100. Current DDR is rated as PC3200. Original RIMM modules were PC600, PC700 and PC800 speeds. Current RIMM modules are rated PC1066. Original DDR2 is designed for 400MHz, 533MHz and 667MHz speeds. Latest DDR2 is designed for 800MHz operating speed.
What does this mean in terms of quantity of data that could be transferred per second? Taking information from a variety of memory manufacturers sites we can make a table to show some comparisons of peak memory performance:

Type of RAM	PC Rating	RAM Speed in MHz	Peak Throughput in MB/sec
SDRAM	PC100	100	800
SDRAM	PC133	133	1100
RIMM	PC800	400	1600
RIMM	PC1066	533	2100
DDR	PC1600	200	1600
DDR	PC2100	266	2100
DDR	PC2700	366	2700
DDR	PC3200	400	3200
Dual Channel RIMM	PC800	400	3200
Dual Channel RIMM	PC1066	533	4200
Dual Channel DDR2	PC2-3200	400	6400
Dual Channel DDR2	PC2-4200	533	8400
Dual Channel DDR2	PC2-5300	667	10600
Dual Channel DDR2	PC2-6400	800	12800

Memory Latency

Now we are getting technical... In the simplest terms Latency is delay. In a computer it is the inevitable pause between asking for some data and having that data available to be used. To give a real life example I looked at the Newegg site and found a couple of pairs of 1GB DDR PC3200 RAM modules which would look nice in my system, but am I better off ordering the OCZ Gold RAM with 2-3-3-8 timing or the Mushkin High-Performance RAM with 2-3-2-6 timing? What the heck do those numbers mean anyway?
I'll try to offer a simple explanation, but if all this terminology really makes your eyes glaze over then just remember if *all else is equal* then the lower the numbers are, the better the RAM will perform. Then skip to the next section. For the rest of us here goes:

Data is stored in your computer's memory chips in a similar way to storing data in a spreadsheet - it is organized in rows and columns and is sequential along a row. For example in a 16Mbit chip there would be 4,194,304 address locations or "cells" arranged in 2048 rows and 2048 columns. Each cell in the chip holds four bits of data. Part of the chip might look like this:

Address	Column 1	Column 2	Column 3	Column 4
Row 1	1101	1001	0100	0110
Row 2	1011	1000	1100	0000
Row 3	1111	1010	0101	1100
Row 4	1011	0011	1010	1100

Keep in mind the ones and zeroes are represented by **voltage levels** in the form of electrical charge in a capacitor in the real chip and that these are being refreshed repeatedly. To read the data in a particular cell in our 2048x2048 chip the computer needs to indicate which Row the data is in and then indicate the Column that holds the cell containing the required data. It does this by issuing (in binary) an "address" for the Row and then the Column using the same 11 bit address bus in each case (because it takes 11 bits to count up to 2048 in binary). For example to read the data in the green cell in the diagram the computer must first address Row 3 (highlighted in yellow) and after that address is fixed it addresses Column 2 (highlighted in blue). Can you see a delay here already?

Because everything is taking place at mind-boggling speed there has to be a 'pause' between issuing the Row address and issuing the Column address to allow the voltages to stabilize. If the pause is not long enough the Column address could be corrupted by voltage remaining from the Row address resulting in the wrong data being read. Both the Row address and the Column address are "latched" into the memory chip by signals called "strobes", so we have a Row Address Strobe (**RAS**) and a Column Address Strobe (**CAS**). The necessary delay between them is called the RAS-CAS delay or **TRCD**. All the delays referred to are measured in clock cycles rather than actual time intervals.

Once the cell data (1010) has been read the next four bits of data required are (usually) in the same Row but in the next Column along so only the Column address needs to be changed. Again there must be a delay while the previous address 'evaporates' and the new address voltages stabilize before the address can be latched. This delay is called the CAS Latency or **CL**.

Similarly, once all the required data in a row has been read a different row needs to be addressed. Since the contents of the cells have to be refreshed and this is done on a Row by Row basis there is another delay required called the RAS Pre-charge time or **TRP**.

The memory in your computer is not active *all the time* and during the (tiny) intervals of inactivity certain parts of the memory are shut down to help prevent the chips from overheating. This introduces a delay when they need to be activated again. This is called the "Active to Pre-charge" delay or **TRAS**.

Finally there is another delay that must be allowed for, which is the delay between the computer selecting a particular memory chip (as there will be many chips making up your RAM) and being able to issue a command to that chip. This is called the **Command Rate** and for some reason seems to be without an acronym.

So coming back to the real world and our examples from Newegg can you guess what the quoted "timing" numbers are? That's right - they are the delays or latencies we've just discussed. Here's how a typical timing specification might look:

2-3-2-6-1T

- The first number (2) is **CL**, the CAS Latency. This value has the most effect on system performance. It is usually 2, 2.5 or 3 for DDR memory.

- The second number (3) is **TRCD**, the RAS to CAS delay. Not as critical as CL, it is usually 2,3 or 4 for DDR memory.
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- The third number (2) is **TRP**, the RAS Pre-charge delay. This value has similar effects to TRCD.
-
- The fourth number (6) is **TRAS**, the Active to Pre-charge delay. This value affects stability more than performance. Typically between 5 and 8 for DDR memory.
-
- The last figure (1T) is the **Command Rate** and is often omitted, as it is almost always 1T. For slow RAM it would be 2T. Strangely some over-clockers get very good results by deliberately setting the Command Rate to 2T even with low latency RAM as it allows them more flexibility when tweaking the other latencies and bus speeds.

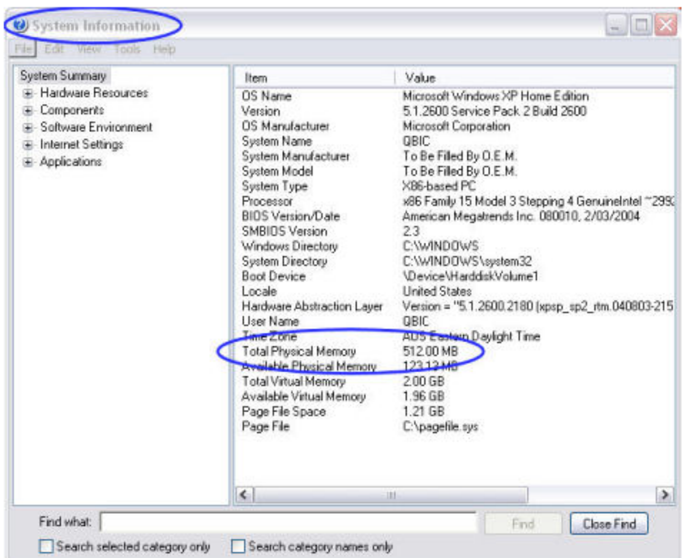
Note that the numbers are valid only for the rated clock speed and will also be quite different for different types of RAM.

The real life examples were 2-3-3-8 and 2-3-2-6 both of which are good for DDR at 400MHz, but I can now see that the Mushkin 2-3-2-6 RAM may be more stable under heavy load than the OCZ RAM. So I can check the price differential and consider whether that is likely to be an important factor for my computer usage.

These latencies and timing figures have to be entered in the BIOS when the RAM is installed - the reason you've probably never had to do this is they are programmed into the SPD EEPROM on the RAM module and the BIOS reads the values automatically (unless set to manual). If you have two RAM modules with different timing figures then the BIOS takes the highest figure (slowest setting) to work with. The timing figures are manufacturers recommendations for successful operation, there is no law which says the memory module will not work with different timing and this is fertile ground for over-clockers to experiment. They switch the BIOS memory settings to Manual so the SPD is ignored and insert their own figures in the BIOS. I am NOT suggesting anyone attempt to do this, unless you know **exactly** what you are doing. You can destroy your RAM with inappropriate settings.

How to Identify your RAM

To properly identify your RAM you need to know the total memory size in Megabytes(MB), how many memory modules there are, the type of RAM you have, its speed and ideally its manufacturer. There are a number of different ways you can find some or all of this information.



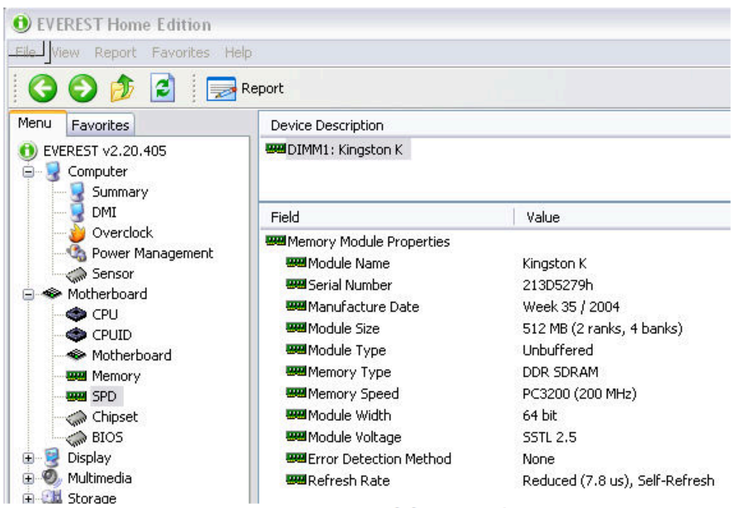
Using Systeminfo.exe to see the total amount of RAM

Below are some free utilities that can be used to determine the amount of memory currently installed and the types of hardware installed:

- The Windows **System Information** command, as shown above, allows me to see how much total memory I have installed in my computer.
- **SpeedFan** allows me to check what RAM I have: Launching SpeedFan from its desktop icon reveals I have version 4.27 installed. The program takes a few seconds to gather information then settles down at the 'Readings' screen where it shows you fan speeds and component temperatures. Click on the 'Info' tab and click the 'Read info' button. This gathers information and displays it in the 'DIMM info' box. Scroll up and down to see all the information. As shown below SpeedFan tells me I have only one RAM stick (DIMM #0) and it is DDR, it does not store parity information, and the total size is 512MB. If I had more than one stick there would also be information for DIMM #1, DIMM #2, etc.

SpeedFan 'DIMM info' Box

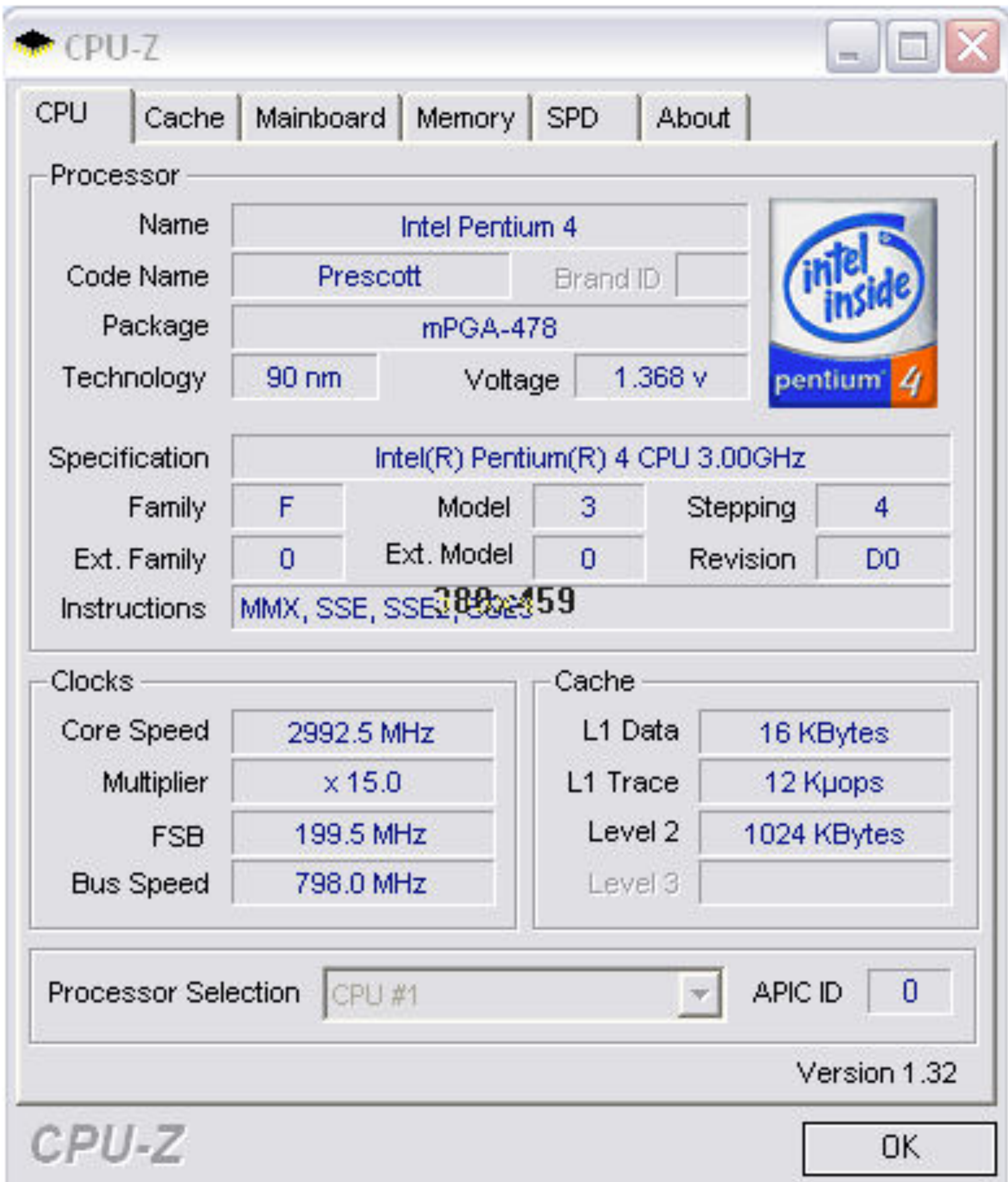
Now let's have a look using **Everest Home Edition**: Start Everest, in the 'Menu' column on the left hand side click on 'Motherboard'. The right hand window should change to show CPU, CPUID, Motherboard, Memory, SPD, Chipset and BIOS icons. Click on the cryptically named 'SPD' icon (for an explanation see the SPD entry in the previous section). As shown below this reveals a wealth of information. The single entry for 'DIMM1' under device description shows I only have one memory stick. The details below show a serial number, date of manufacture, size (512MB), type (DDR SDRAM), speed (PC3200) and other information including the Manufacturer's name (Kingston Technology Company Inc.) and a link to their website. It incorrectly reports I have four DIMM slots when in fact my motherboard only has two. Note that Everest Home Edition is no longer under development and some of the information may be out of date.



Everest Memory Module Properties

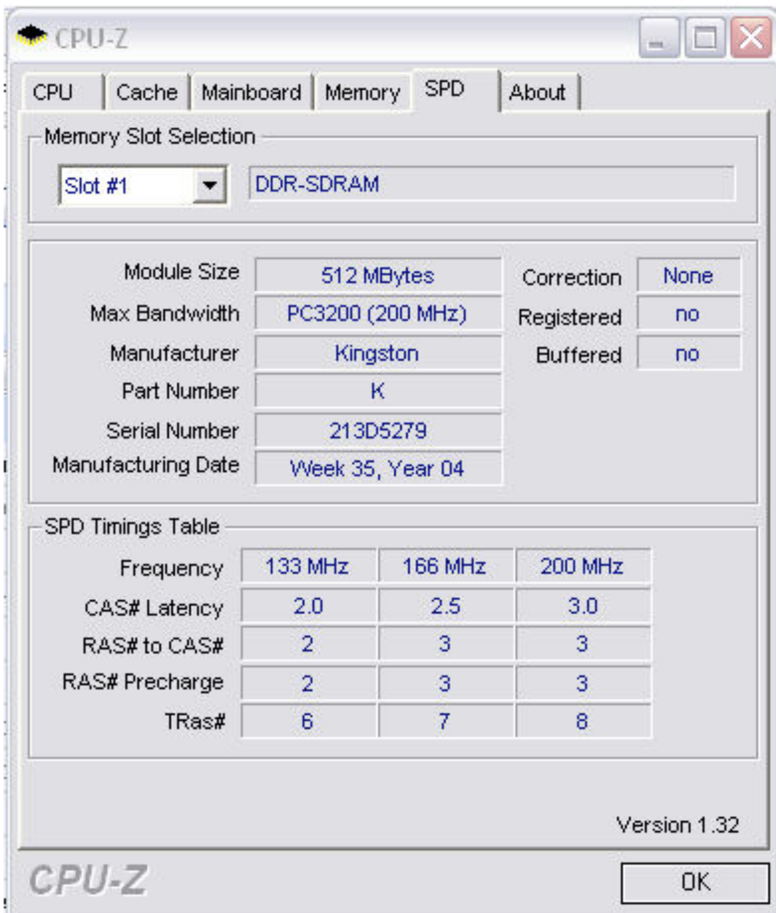
Additional information about the Memory Controller can be found in the 'Motherboard' window by clicking on 'Chipset' and highlighting 'North Bridge'. This will indicate for example whether the Memory Controller can support Dual Channeling, which you will need to consider if you are upgrading.

Finally let's check out our RAM using the freeware program **CPU-Z**. If you downloaded this from the address in the "Required Tools" section you will have a zip file somewhere in your computer. Extract the zip file to a directory called 'CPU-Z' or some name you can remember easily. That's all you need to do, there is no installation process. To run CPU-Z navigate to the CPU-Z folder and double click the **cpuz.exe** file. This will run the program and present you with a report window which looks like this:



CPU-Z Opening Screen

We're interested in the RAM at present so click the 'Memory' tab. Here it tells me I have 512MB of DDR SDRAM on a single channel, running at 133MHz. It tells me the ratio of the FSB to the DRAM clock is 3:2 when I would have expected it to be 1:1 (I fixed this later - see under "Look in the BIOS" below). This tab also tells me the timing figures are 2-2-2-6 @133MHz. (See the 'Memory Latency' section for an explanation of these figures). Now click the 'SPD' tab.
Information for Slot #1 is displayed, a pull down menu lets you select slot #2, slot #3, etc., which in my case say "Empty". The rest of the display looks like this:



CPU-Z SPD Screen

How much RAM do you need?

"640K should be enough for anybody." - Bill Gates 1981

Ironic that this quote should come from the founder of Microsoft - the company whose Windows operating system goes through computer resources like kids go through birthday cake.

Older operating systems required a lot less RAM then moden system. Modern operating systems, and their hardware, require quite a bit more to properly operate. As a standard, most computers these days should have a minimum of 4 GB (Gigabytes) in order to properly run. In my opinion, though, the sweet spot is 8GB, which should allow you to run most applications and games in Windows.

For those who are doing heavy video editing, graphics design, hard core gaming, or just like to have a lot of programs running, you cannot go wrong with 16GB.

Anything past 16 GB may not provide much of a speed benefit other than being able to run more programs at the same.

Can you have too much RAM?

In modern operating systems and hardware, having a lot of ram won't hurt the system, but you may not actually benefit from it.

For historical purposes, here are the details for using too much ran in older systems. For the most part, noone should be using these systems anymore, so it should not matter.

- Windows 95 and Windows 98 (first edition) do not recognise more than 256MB of RAM - adding more than this can **slow down** your system markedly. There is however a fix for this detailed in an AumHa article - see the references section. If you have more than 1GB of RAM (though I can't imagine why you would) Windows may not start.
  See the Microsoft knowledgebase article here: http://support.microsoft.com/?kbid=184447
- Windows 98SE and Windows ME have trouble with more than 512MB RAM - you may get "Out of Memory" errors or other symptoms.
  See the Microsoft knowledgebase article here: http://support.microsoft.com/kb/q253912/

- Windows 98SE and Windows ME will not run well with more than 1GB of RAM. This may cause "potential system instability" according to Microsoft.

- Some versions of the Award BIOS slow down your system markedly when more than 768MB of RAM is installed.

RAM Explained
https://youtu.be/PVad0c2cljo

What is RAM:
https://youtu.be/NrMmZPg40Ok