HAUPTWERK
VIRTUAL PIPE ORGAN

Technical Data

Technical information on hardware for Hauptwerk

Part 1: polyphony

When you engage several stops on an organ and play a chord, a lot of pipes sound simultaneously. For example, suppose you have 10 stops drawn and you play a 10-note chord (5 keys with each hand). Usually 10 x 10 = 100 pipes will be sounding simultaneously. Since Hauptwerk uses one sample per pipe, playing and holding such a chord in Hauptwerk means that Hauptwerk must play 100 samples simultaneously, and thus consume 100 voices of polyphony.

Since Hauptwerk uses release samples to reproduce the natural decay of the pipes and, optionally, also the acoustic (reverberation) of the room, those samples must continue to play after you release the keys. If the reverberation tails are long, perhaps 2 seconds, then that chord will continue to consume 100 voices of polyphony for an extra 2 seconds after you release the keys. So if you play a fast piece of music, the polyphony demands may be very high. For example, suppose you play chords of 4 notes with 10 stops drawn, at a rate of 5 chords per second, and the average length of the release samples is 2 seconds. You then need a polyphony of 4 x 10 x 5 x 2 = 400 voices.

However, if the samples are 'dry', with no reverberation recorded into the release samples then the release samples will be much shorter - perhaps 0.5 seconds, and you would need a polyphony of only 4 x 10 x 5 x 0.5 = 100 voices to play the same piece. So dry samples require much less polyphony than 'wet' samples. However, wet samples capture the natural acoustic of the room, which is often much more realistic for listening at home, especially with historic organs where the acoustic is an integral part of the sound.

Hauptwerk has an advanced ***polyphony management*** system, which allows you to specify the maximum polyphony that your computer hardware can achieve after testing it initially. When Hauptwerk reaches that limit, no more pipes are allowed to sound, preventing the system becoming overloaded and the audio breaking up (very important for live recitals!). A little before the limit is reached, Hauptwerk attempts to fade out some of the most inconspicuous release samples, so that even reaching the polyphony limit is extremely rare. In practice this means that you can choose your computer hardware to support the polyphony that you will need for average playing, and let Hauptwerk's polyphony management system handle extreme loads safely, usually with no audible loss of quality.

The limit can be fine-tuned separately for each instrument, and processor-intensive features can be enabled or disabled separately for each instrument, so that you can get the best balance of performance and realism that your computer hardware can handle for the instrument.

If, for example, you expect to play a instrument with 2 second reverberation, and anticipate that you would normally not use more than about 10 stops with 3-note chords in each hand (6 keys), at a rate of 3 chords per second, then, as above, you would need a true polyphony of 6 x 10 x 3 x 2 = 360. As a rule of thumb, we would recommending choosing your computer hardware to be able to handle 3 times that polyphony, which would give optimal performance for the vast majority of the time, while Hauptwerk's polyphony management system will handle extreme loads unobtrusively and safely. Hence, with this example, you should choose a computer that you would expect to be able to handle about 1000 simultaneous pipes.

As a rough guide, we would recommend that for average use you might choose the overall maximum polyphony required as follows:

- 500+ voices of polyphony for medium-sized organs (30 ranks or less) with dry samples.
- 1000+ voices of polyphony for large organs (30-60 ranks) with dry samples.
- 800+ voices of polyphony for medium-sized organs (30 ranks or less) with wet samples.
- 1700+ voices of polyphony for large organs (30-50 ranks) with wet samples.
- 2400+ voices of polyphony for extremely large organs (50 or more ranks) with very long reverberation (the largest cathedral organs).

The polyphony is the main factor that determines the processing power you need. In summary it depends on:

- How 'wet' the most reverberant instrument you plan to use will be (average decay time).
- The maximum number of stops you will engage at once (more stops tend to be drawn simultaneously on larger organs).
- The type of music you will play - speed and number of simultaneous notes.

Part 2: memory

The amount of memory your computer has primarily determines the maximum size instrument that can be loaded in Hauptwerk.

In order to achieve the very high polyhony necessary to model organs effectively, Hauptwerk needs to keep all of the samples in memory. Hard-drives are very slow compared to memory, and many drives would be required in parallel to achieve an equivalent polyphony by streaming samples from the hard-disk. Thus it usually works out considerably cheaper in terms of computer hardware to keep the samples in memory, particularly because computer memory is very cheap now.

Since Hauptwerk keeps all samples in memory, you **must** have sufficient physical memory free to load the largest instrument you intend to use entirely into memory. If you do not have enough memory, you will either get an 'out of memory' error when loading the instrument or some of the samples will be 'paged' temporarily to disk by the operating system, in which case it will not be possible to access them quickly enough when they are required, causing glitches in the the audio output.

The amount of free memory required for a given instrument is usually stated as a prerequisite by the creator of the instrument. We also try to give a basic guide figure for each Hauptwerk version 3 or version 2 instrument in our list of third-party virtual instruments. Roughly speaking, it depends upon:

- The number of samples.
- The average length of the samples. Dry samples usually require less memory because the release samples are shorter.
- The channel format of the samples - stereo or mono. Stereo requires twice as much memory as mono.
- The sample rate - 44.1, 48 or 96 kHz. Higher rates require more memory.
- The sample resolution - 16, 24 or 32-bit.
- Whether the instrument has multiple samples per pipe.

When you load an instrument in Hauptwerk you can choose not to load some of the ranks of pipes, so that you can fit a subset of an instrument into the memory available.

You can also choose to load 24 and 32-bit samples in 16-bit (the default) or 20-bit, very significantly reducing the memory requirement for 24-bit samples. The audible quality loss will be small since Hauptwerk performs all mixing and signal processing in 32-bit and produces output in the highest resolution supported by the audio/sound card, so the effective resolution is usually much higher than 16-bit even if the samples are loaded in 16-bit.

Various further per-rank memory saving options are available, such as loading only the first loop in a sample, loading a stereo sample in mono, loading at most one sample per pipe, or truncating its release samples, although they come at the expense of some realism.

The following is a rough guide to the types of instruments that might typically be usable in full within a given amount of memory:

- 1 GB: dry, mono organs <50 ranks; dry, stereo organs <30 ranks; wet, stereo organs <20 ranks.
- 2 GB: dry, mono organs <120 ranks; dry, stereo organs <60 ranks; wet, stereo organs <40 ranks.
- 3 GB: almost all dry organs; wet, stereo organs <50 ranks.
- 4 or 8 GB: very large and/or very wet, stereo organs and almost all dry organs.

However, please look at the requirements given by the instrument creators for the specific instruments that are of

interest to you. The St. Anne's, Moseley organ instrument included with Hauptwerk requires at least 1 GB of installed memory to be loaded fully, but its Great division alone can can be used on a computer with only 512 MB of memory.

The maximum amount of memory that can be installed in a computer is determined by its hardware (motherboard) and the operating system. Older computers are commonly limited to 2 GB while newer models of Apple Macs and PCs can handle 32 GB or more.

On the Apple Mac platform, Hauptwerk is fully supported on OS X 10.5 'Leopard' and 10.4 'Tiger'. We recommend Leopard over Tiger, since it has significant performance and stability improvements internally that are relevant to Hauptwerk and only Leopard can support 64-bit Hauptwerk. OS X Leopard has simultaneous 64-bit and 32-bit support built natively into it. Unlike Windows, there are not separate 64-bit and 32-bit versions of OS X, and no separate 64-bit drivers are needed for 64-bit Hauptwerk. 64-bit Hauptwerk for OS X requires a 64-bit Intel Mac (all Mac Pros and all Macs made since about November 2006 are 64-bit capable), and allows an almost unlimited amount of memory to be used.

32-bit versions of Windows Vista and XP are limited to 2 GB or 2.7 GB, but a Windows configuration setting must be changed to enable support for the third GB.

64-bit PCs running 64-bit Windows Vista or Windows XP Professional x64 Edition (64-bit) can theoretically access many GBs of memory, subject to the limit for the motherboard. A 64-bit computer and 64-bit Windows Vista are thus recommended when buying a new PC system, provided that good drivers exist for the sound/audio and MIDI interfaces you intend to use. However, note that some audio and MIDI interfaces are not fully compatible with 64-bit Windows, and some only work properly with 32-bit software, so the memory limit is sometimes effectively 4 GB.

The clock rate of the memory makes a significant difference to the performance of Hauptwerk. Use the fastest memory that your system supports reliably. For example, if your motherboard can support PC2100, PC2700 and PC3200, use PC3200 memory throughout. In general on PCs, we recommend using ECC memory if your motherboard supports it, since ECC memory should lead to improved system stability. All computer memory will have very occasional data errors which can lead to crashes or other unexpected results. ECC memory attempts to detect and correct such errors automatically.

For 64-bit systems that support dual-channel memory, ensure that both memory channels have separate but matching memory boards, which can also give a significant performance improvement. For example, if you have a single 64-bit processor that supports dual-channel memory, and you require 4 GB of memory in total, install two 2 GB memory boards - one into a slot for each memory channel, rather than a single 4 GB board. All available memory channels and processors should be loaded equally for best performance (Hauptwerk is optimised for NUMA, and can take advantage of such memory configurations), and memory boards should be matched for maximum reliability.

When buying a computer it is also a good idea to consider allowing room for expanding the memory at a later date, i.e. buying a system with more memory slots than you need initially.

Part 3: processors

The performance of the processor(s) primarily determines the polyphony that can be achieved in Hauptwerk.

Hauptwerk's basic static polyphony is defined and measured for mono samples, panned into stereo in real-time, and for unenclosed pipes (those not in swell boxes), with all of Hauptwerk's realism features enabled. There are several additional factors within Hauptwerk that affect the polyphony that can be achieved on a given system:

- Using true stereo instruments decreases the polyphony that can be achieved by about 20 percent. (Note that this differs from Hauptwerk 1, whose 'simulated stereo' mode reduced polyphony.)
- Using pipes enclosed in a virtual swell box decreases the polyphony by about 30 percent due to the additional overheads of the digital filters used in Hauptwerk's swell box model, which are applied to each pipe individually. Note that the swell box model filters can be disabled, leaving just volume adjustment by the virtual swell box.
- Hauptwerk also applies 'harmonic shaping' filters to control the tone of each pipe individually for voicing, tremulants and flow modeling. These can also be disabled, giving approximately a further 30 percent gain in polyphony, although the realism of tremulants will be particularly impaired, and we recommend this only as a last resort.
- You can disable interpolation entirely, giving fixed pitch sample play-back and a loss of some realism, but typically doubling or even tripling the polyphony that can be achieved, and allowing even very large instruments to be used on older or low-cost computers.

Hauptwerk is specially optimised to be able to take advantage of multi-core processors, multi-processor systems, 64-bit processors and NUMA (non-uniform memory access). 64-bit processors are also a prerequisite (only) if you plan to use more than about 3 GB of memory with Hauptwerk.

The total number of processor cores, memory bandwidth, processor level 2 cache size and the processor core clock speed are the main factors that determine the polyphony that can be achieved with Hauptwerk.

On Windows PCs the audio interface and its drivers can also have a large effect on polyphony. In particular, note that a good basic audio interface and driver (e.g. an E-MU 1212M) can as much as double polyphony over a low-cost sound card in a PC. This is not usually the case on Apple Macs because high-performance audio is built into Mac OS X and there is much less dependency on audio drivers.

Although Hauptwerk can be used effectively on a 1.25 GHz G4 Mac or a PC with a Pentium III or AMD Athlon processor, a system with an Intel Core 2 Duo processor would be the minimum that we would recommend for a new computer, since they are available relatively inexpensively and perform so well with Hauptwerk, even with large organ instruments. 64-bit processors (such as the Intel Core 2 dual and quad-core range or their Xeon equivalents) also have the potential to be able to access more than 3 GB of memory. On Windows PCs, the AMD Athlon 64 X2 and Opteron processors also work well with Hauptwerk, but, at the time of writing, the Intel Core 2 / Xeon processors out-perform them with Hauptwerk by a very large margin.

For best performance, if you are buying a new computer, we recommend buying one with processors with at least 1 MB of level 2 cache per processor core. The Intel Core 2 Duo E6600 and E6700 models (2.33 and 2.66 GHz) have 4 MB of level 2 cache shared between their two cores, which is good. The more level 2 cache, the better.

The Intel Xeons (54xx series) are the multi-processor equivalents of the Core 2 range, and a dual-processor system using these is ideal for almost the largest conceivable organs with all of Hauptwerk's realism features enabled, including large cathedral organs and very large theatre organs. The Apple Mac Pro is such a computer, which we strongly recommend if you are looking for the ultimate computer to run Hauptwerk.

However, once again we wish to stress that **these recommendations are only intended as a guide if you are buying a new computer**. Hauptwerk will perform very well indeed with even quite large instruments (30 ranks or so) on existing computers with a single 2 GHz processor or faster and all realism features enabled, provided that you have sufficient memory for the instrument you wish to use. To emphasize this fact, we recorded some of our audio demos in real-time on a PC with a modest 2.8 GHz Intel Pentium 4 processor.

You can still easily use Hauptwerk on older computers (such as 1 GHz Pentium III PC or 1.25 GHz G4 Mac) with large organs and with excellent results and incredible performance by simply **disabling some of the audio realism features** such as interpolation and per-pipe filters, of course, at the expense of some realism. With interpolation, per-pipe filters and multiple sample loop playback disabled, Hauptwerk will typically be able to achieve about **three times the polyphony** than with all features enabled.

The following gives a very rough guide to the approximate static polyphony in simultaneous pipes that can normally be expected with some modern processors, based on our benchmark tests (mono samples panned into stereo, unenclosed pipes, all Hauptwerk features enabled, 12 milliseconds buffer latency).

Apple Macs:

- Apple Mac Pro (2 x 2.66 GHz Intel Xeon dual-core processors), Apple memory, Mac OS X 10.5 'Leopard': **5000-6500**.
- Apple iMac (1 x 2.66 GHz Intel Core 2 Duo processor), Apple memory, Mac OS X 10.5 'Leopard': **2500-3500**.
- Apple MacBook Pro (1 x 2.66 GHz Intel Core 2 Duo processor), Apple memory, Mac OS X 10.5 'Leopard': **2500-3500**.
- Apple PowerMac G4 (2 x 1.25 GHz G4 processors), Apple memory, Mac OS X 10.5 'Leopard': **375-450**.

Windows PCs:

- Intel Core 2 Q6600 processor (2.66 GHz, 8 MB shared L2 cache, quad-core), PC5300 ECC DDR2 memory split equally among two memory channels, 64-bit Windows Vista or XP: **5000-6500**.
- Intel Core 2 Duo E6700 processor (2.66 GHz, 4 MB shared L2 cache, dual-core), PC5300 ECC DDR2 memory split equally among two memory channels, 64-bit Windows Vista or XP: **3500-4000**.
- Intel Core 2 Duo E6700 processor (2.66 GHz, 4 MB shared L2 cache, dual-core), PC5300 ECC DDR2 memory split equally among two memory channels, 32-bit Windows Vista or XP: **2300-3000**.
- Two AMD Opteron 275 dual-core processors (2.2 GHz, 1 MB L2 cache per core), PC3200 memory split among all four processor memory channels, 64-bit Windows Vista or XP: **3500-4500**.
- Two AMD Opteron 275 dual-core processors (2.2 GHz, 1 MB L2 cache per core), PC3200 memory split among all four processor memory channels, 32-bit Windows Vista or XP: **3000-4000**.
- AMD Athlon 64 X2 4400+ dual-core processor (2.2 GHz, 1 MB L2 cache per core), PC3200 memory split equally among two memory channels, 64-bit Windows Vista or XP: **1700-2200**.
- AMD Athlon 64 X2 4400+ dual-core processor (2.2 GHz, 1 MB L2 cache per core), PC3200 memory split equally among two memory channels, 32-bit Windows Vista or XP: **1500-2000**.
- Intel Pentium 4 2.8 GHz single-core processor with 512 KB of L2 cache, 32-bit Windows Vista or XP: **750-1000**.

On Windows PCs, the exact result achieved also depends significantly on the sound/audio interface, its drivers and the motherboard. These benchmarks were made using good basic professional audio interfaces using their native ASIO drivers.

Part 4: audio interface

Functionally, the computer's audio (or sound) interface determines:

- The maximum number of audio output channels to which pipe ranks can be routed from Hauptwerk.
- The sample resolution in which Hauptwerk will produce output (16, 24 or 32-bit). Hauptwerk automatically uses the highest resolution supported by the interface.
- The instruments that can be used, by way of its maximum sample rate. Hauptwerk will only allow an instrument to be used if the audio interface supports the sample rate used for its samples (technically speaking, that is in order to avoid the overheads of real-time anti-aliasing filters).
- On Windows platforms: the types of audio drivers that can be used by Hauptwerk. Hauptwerk supports both ASIO and DirectSound on Windows, with ASIO usually giving lower latency (delay from pressing a key to hearing the sound). Generally only professional audio interfaces and high-end consumer sound cards support ASIO natively.
- On Windows platforms: the minimum latency that can be achieved reliably. Usually professional audio interface ASIO drivers are better, but the results still vary greatly between individual interfaces and their drivers, from as little as 1.5 milliseconds to more than 50 milliseconds.
- On Windows platforms: the maximum polyphony that can be achieved reliably (number of simultaneous pipes). The interface's drivers can have a large effect on polyphony, as much as doubling or halving it between different interfaces and drivers.

Mac OS X has its own high-performance professional-grade audio system called 'CoreAudio' built in, so there is much less dependency on driver quality on OS X, and latency (delay from pressing a key to hearing the sound) and polyphony should not be affected significantly by the choice of audio interface.

On Windows PCs: the audio interface and the quality of its drivers (either ASIO or DirectSound) are the biggest factors determining the lowest latency that can be achieved, and also have a huge effect on polyphony. ASIO drivers will usually give a much lower latency than DirectSound drivers, and tend to be much more resilient. If you want high polyphony and low latency, please **buy a good basic professional/semi-pro audio interface, rather than economising on the most important part of the whole system**! A low-cost sound card or emulated/third-party drivers will not usually give especially high performance.

The quality of the audio interface itself (and its digital-to-analog converters) makes an enormous difference to the audio quality you will hear from Hauptwerk. We would strongly recommend using professional audio interfaces that support at least 24-bit, 96 kHz audio with good quality drivers.

Any audio interface you use must natively support the sample rates used by the organs you wish to load into Hauptwerk (typically 44.1 kHz, 48 kHz and 96 kHz). Note that the default built-in sound output found on many computers, including Apple Macs, only supports 44.1 kHz and so cannot be used with instruments requiring other sample rates, such as 48 kHz. The sound quality from most computers' built-in outputs is also not usually especially high.

The number of audio outputs required depends on how you wish to amplify the output; for use in churches and reverberant spaces, where dry instruments would normally be preferred, using many audio channels with separate amplifiers and speakers gives a much better spatial effect, and allows the sound to mix more naturally within the room acoustic. However, for listening at home to instruments recorded in their original acoustic, a single stereo pair is often more appropriate. Multi-channel audio output facilities are only available in the Advanced Edition of Hauptwerk.

Part 5: MIDI interface

If you wish to play or control Hauptwerk in real-time then you need some form of MIDI interface for the computer. Hauptwerk receives MIDI input to control its keys and console controls, and optionally produces MIDI output to drive external MIDI console hardware, such as solenoid-actuated or illuminated draw-knobs or tabs, or real external ranks of pipes.

Many audio interfaces, such as the Echo Audiofire range have one or more MIDI input and MIDI output ports built in. Many consumer PC sound cards also have such a such a facility by attaching a MIDI-gameport adapter lead.

However, if you wish to connect several MIDI input devices to Hauptwerk, such as several MIDI keyboards and MIDI draw-knob encoders, then you will usually need either a multi-port MIDI interface or a MIDI merge box. Multi-port MIDI interfaces are preferable because their timing is usually more accurate and they are less easily overloaded. You need to buy an interface that has at least as many MIDI input ports as you have MIDI input devices to connect.

MIDI output is simpler because most MIDI devices allow the MIDI connections to be 'chained', but a MIDI interface with multiple output ports will still usually provide better timing and error-resilience. Note that MIDI output facilities are only available in the Advanced Edition of Hauptwerk.

Theoretically any MIDI interface that is compatible with your computer hardware and operating system should work with Hauptwerk, and we have had very few users who have ever had problems with any MIDI interfaces.

Unless specifically advised to do otherwise, it is usually best to ensure that the latest versions of the manufacturers' drivers and firmware are installed.

If you only intend to use Hauptwerk with a MIDI sequencer, then you do not necessarily need any hardware MIDI interface. Apple Mac OS X has a built in 'virtual MIDI cable' called the *IAC Driver*. However, for Windows PCs with non-VSTi compatible sequencers you will need to install a 'virtual MIDI cable' driver yourself, such as MIDI Yoke (compatible with 32-bit software) or LoopBe1 (compatible with both 32-bit and 64-bit software).

Part 6: disk drives

Since Hauptwerk stores all audio data in memory, rather than streaming audio samples from hard-disk, provided that sufficient memory is installed in a computer, the type and speed of its hard-disks should have no significant effect on Hauptwerk's real-time audio performance (polyphony).

Principally, the speed of the disks determines the time taken to load a instrument into memory. Other operations involving files are also affected to a lesser degree, such as:

- Loading and saving registration combination banks.
- Loading different temperaments.
- Recording the audio output from Hauptwerk.

If you use Hauptwerk with a sequencer, then the speed of the disks may affect the performance of the sequencer, which may in turn affect the performance of Hauptwerk to some degree.

If you consider loading times to be important, then we recommend you use the fastest disks available for your hardware, such as 7,200 or 10,000 RPM drives with 16 MB or more of cache memory. Currently we would recommend SATA drives, which are supported by the vast majority of modern computers, and are generally available and reasonably priced.

Certain configurations of RAID disk arrays can also give very high disk performance, although some of the RAID controllers included on PC motherboards do not perform especially well, and additional dedicated RAID controller cards might be required for best performance. RAID 1 or RAID 5 arrays are recommended for both security and speed. (RAID 0 arrays are fast, but give the least data security since all data would be lost if any one disk failed. RAID 0+1 and 1+0 give good data security and performance but require at least four hard drives.) For live installation in an environment where fault-tolerance is critical, such as for public performance, two or more matching disks in a RAID 1 array are recommended.

On Apple Macs that support multiple disk drives, such as the Mac Pro range, Mac OS X includes a tool called *Disk Utility* which can be used to set up a software-based RAID array. A (software) RAID 1 array on a Mac Pro gives good performance.

Hauptwerk requires a large amount of disk space to allow for installation of instruments, and its cached instrument data. The cached data are used to speed up loading of instruments, and occupy very approximately an additional two-thirds of the amount of disk space occupied by the raw instrument data alone. Hence almost twice as much disk space is required as that for the raw instrument data alone. In general, we would recommend allowing 40-200 GB of disk space if you intend to use a number of different instruments.

We would recommend choosing disks that have at least a three year warranty and good reliability, such as the Seagate Barracuda SATA drives. The disks available from Apple for the Apple Macs are perfectly adequate.

A pair of good-quality high-capacity 7,200 RPM SATA drives (such as the Seagate Barracuda range) in a RAID 1 array used with a good-quality motherboard that has a good-quality onboard RAID controller should provide excellent performance and fault-tolerance at a reasonable cost.

If you are installing Apple Mac OS X from scratch (not usually required), we recommend using the default file system during installation, and avoiding the 'case sensitive' file system (a custom installation option) since some Hauptwerk instruments may not be compatible with it. On Windows PCs we strongly recommend using the NTFS file system (the default for Windows XP and Vista) instead of the older FAT32. FAT32 does not support files larger than 4 GB, which can cause problems for some very large instruments.

