Technical Datasheet: background technical information on computer hardware for Hauptwerk

About this document

This document is intended to supplement the '*Hauptwerk prerequisites*' section in the main Hauptwerk user guide, which can be found on the *Help* menu in Hauptwerk, or on the Hauptwerk website: https://www.hauptwerk.com/support/documentation/.

Please consult that prerequisites section in concert with this document; relevant important information within it isn't duplicated here.

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 (for most 'virtual instruments', a.k.a. Hauptwerk 'organs' or 'sample sets') Hauptwerk uses one audio 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 many people prefer 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 reliably, based on an initial test. 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 least conspicuous 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 normal playing, and let Hauptwerk's polyphony management system handle occasional extreme loads safely, usually with no audible loss of quality or realism.

The limit can be fine-tuned separately for each virtual instrument, and processor-intensive features can be enabled or disabled separately for each virtual 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 virtual instrument with 2 second reverberation, and you 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 recommend choosing your computer hardware to be able to handle at least 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.

It's also important to note that the use of couplers effectively multiplies the number of stops that are sounding. For example, if you have 4 stops drawn on the Great division and another 5 on the Swell, and you have the Swell to Great coupler drawn and play on the Great, then effectively you have 4 + 5 = 9 stops playing from the Great. Sub-octave and Super-octave couplers similarly multiply the effective numbers of stops sounding. These must be taken into account when planning the polyphony you require.

Many popular recent wet virtual instruments also feature 'surround sound', in which separate sets of stereo samples are included for every pipe for several different microphone/listening positions, such as 'front' and 'rear' versions of each pipe. It's possible to load such virtual instruments in conventional stereo (as opposed to 'surround') by disabling one or more of the microphone/listening positions for some or all ranks when loading the virtual instrument. However, if you wish to use those virtual instruments in full 'surround' then you need to multiply your polyphony requirements by the number of different sets of microphone/listening positions you will be loading. For example, if a virtual instrument has samples for two stereo microphone/listening positions per pipe, and if you wish to use both of them simultaneously for 'surround' listening (through two pairs of speakers, or by mixing them together to a single pair of speakers), then the virtual instrument would require approximately twice as much polyphony as an equivalent conventional stereo one.

If you plan to use several virtual instruments (either now, or over the lifespan of your computer hardware), then when planning the computing power needed, you should of course take the maximum polyphony that you calculate for any of your planned virtual instruments.

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As a very, very rough guide, we would recommend that for average use with current Hauptwerk versions and virtual instruments you might choose the overall maximum polyphony required as follows:

- 500+ voices of polyphony for medium-sized virtual instruments (30 ranks or less) with dry samples.
- 1000+ voices of polyphony for large virtual instruments (30-60 ranks) with dry samples.
- 2000+ voices of polyphony for extremely large virtual instruments (60 or more ranks) with dry samples, such as very large theatre organs.
- 1000+ voices of polyphony for medium-sized virtual instruments (30 ranks or less) with wet stereo samples.
- 2000-4000+ voices of polyphony for large virtual instruments (30-50 ranks) with wet stereo samples, or medium-sized virtual instruments with surround-sound samples.
- 4000-8000+ voices of polyphony for extremely large virtual instruments (50 or more ranks) with very long reverberation (the largest cathedral organs) and stereo, or surround, samples.

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

- How 'wet' the most reverberant virtual instrument you plan to use will be (average decay time).
- Whether the virtual instruments support ‘surround’ sound, and whether you plan to use it.
- The maximum number of stops (multiplied by the maximum number of couplers) 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.

System memory (RAM)

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

In order to achieve the very high polyphony necessary to model organs effectively, Hauptwerk needs to keep all of the audio samples for a virtual instrument in RAM at all times while the instrument is being used. Hard-drives are very slow compared to RAM, and many hard-drives would be required in parallel to achieve an equivalent polyphony by streaming samples from the hard-disk. Even SSDs (solid-state drives) and flash memory (as used in USB memory sticks) wouldn’t be fast enough for the polyphony that most people would need. It usually works out considerably cheaper in terms of computer hardware to keep the samples in RAM, particularly because computer memory is relatively cheap, and thus Hauptwerk is designed to work that way, rather than streaming samples from drives.

Since Hauptwerk keeps all samples in RAM, ***you must have sufficient physical RAM free to load the largest instrument you intend to use entirely into memory***. If you don't have enough memory, you will be warned when loading the instrument. If you choose to ignore the warning and continue loading then some of the data might be 'paged' temporarily to disk by the operating system, in which case it will probably not be possible to access them quickly enough when they are required, probably resulting in glitches in the audio output and/or extremely sluggish performance.

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 instrument in the list of virtual instruments on our website. Very roughly speaking, it depends upon:

- The number of samples.
- The average length of the samples. Dry samples usually require less memory because the release tails are shorter.
- The channel format of the samples – surround, stereo or mono. Stereo requires twice as much memory as mono and four-channel surround twice as much again.
- The sample rate – 44.1, 48 or 96 kHz. Higher rates require more memory.
- The sample resolution – 16 or 24-bit.
- Whether the instrument has multiple release or attack 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-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 anyway, and it always produces output in the highest resolution supported by the audio interface, so the effective resolution is usually much higher than 16-bit even if the samples (ranks) themselves are loaded into memory in 16 or 20-bits.

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 release sample per pipe, or truncating its release samples, although they come at the expense of some realism. All of the available options are covered in detail in the ‘*Loading organs*’ section in the Hauptwerk user guide.

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

- 2-4 GB: dry stereo virtual instruments <40 ranks; wet stereo virtual instruments <30 ranks.
- 8 GB: medium-sized wet stereo virtual instruments; small surround virtual instruments; almost all dry virtual instruments.

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- 16-24 GB: very large wet stereo virtual instruments; medium-sized surround virtual instruments.
- 32-64 GB: extremely large surround virtual instruments.

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 included with Hauptwerk requires at least 2 GB of installed memory to be loaded in full, for example.

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 4 or 8 GB whilst recent models can usually handle 16 GB or more.

On the PC platform, to use more than about 2 GB of RAM you need a 64-bit capable PC (as opposed to 32-bit) running a 64-bit edition of Windows. Most PCs made since about 2007 are 64-bit capable.

On the Mac platform, Hauptwerk requires a 64-bit capable Intel Mac (which includes almost all Macs made since about 2006).

The clock rate of the RAM can make a significant difference to the performance of Hauptwerk. If your computer supports several different memory clock rates reliably then use the fastest memory for highest performance. In general on PCs, if system stability is critical to you (for example if you are installing a computer for live performances in a concert hall) then we recommend using ECC (error-checking and correcting) RAM if your motherboard supports it. All computer memory will experience very occasional data errors which can lead to crashes or other unexpected results. ECC memory attempts to detect and correct such errors automatically.

For computers that support dual or triple-channel memory, ensure that all memory channels have separate but matching memory boards, which can also give a significant performance improvement. For example, if you have a single processor that supports dual-channel memory, and you require 16 GB of memory in total, install two 8 GB memory boards - one into a slot for each memory channel, rather than a single 16 GB board. All available memory channels and processors should be loaded equally for best performance (Hauptwerk is optimized 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 RAM, or with more RAM slots, than you need initially.

Processors (CPUs)

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, compared to mono samples.
- 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 that 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 optimized to be able to take advantage of multi-core processors, multi-processor systems, 64-bit processors and NUMA (non-uniform memory access).

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

(On the PC platform the audio interface and its drivers can also have a large effect on polyphony. In particular, note that a good basic 'semi-pro' or 'pro' audio interface with an ASIO driver can as much as double polyphony over a PC’s built-in audio output. This is not usually the case on Apple Macs because high-performance audio is built into Mac OS X and there is much less dependence on audio drivers.)

Generally speaking, recent processors will usually significantly out-perform older processors of the same clock speed and number of cores, since processor technology advances rapidly. If buying a new computer to run Hauptwerk we would recommend buying a recent one with at least four CPU cores (quad-core) and with plenty of processor cache. On Windows PCs, both the recent Intel and AMD processors should work well with Hauptwerk, but, at the time of writing, we have found that the higher-specification Intel processors (i7, i5 and corresponding Xeon models) out-perform the higher-specification AMD models for Hauptwerk by a significant margin.

However, 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 moderately-sized instruments (30 ranks or so) on older computers with just a single-core processor and all realism features enabled, provided that you have sufficient memory for the virtual instrument you wish to use.

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Also, you can still easily use Hauptwerk on older computers with fairly large virtual instruments and with excellent results and 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 it would with all features enabled, for example.

As a very, very rough rule-of-thumb guide to the approximate static polyphony in simultaneous pipes that can normally be expected with recent multi-core Intel processors with a good-quality audio interface and a 64-bit operating system, subtract one from the number of CPU cores then multiply the result by 1200-2500.

Audio interfaces

Functionally, the computer's audio interface determines:

- The maximum number of audio output channels to which pipe ranks can be routed from Hauptwerk.
- Audio quality, as a result of the quality of interface's digital-to-analogue converters (DACs).
- Especially on Windows platforms: the resilience to audio glitches, the minimum latency that can be achieved reliably, and (along with the CPU) the maximum polyphony that can be achieved reliably. On Windows, usually good-quality professional audio interfaces with manufacturer-supplied ASIO drivers are *much, much* better in those regards than built-in PC sound outputs, or 'consumer' audio interfaces, or DirectSound drivers, or third-party drivers.
- The sample resolution in which Hauptwerk will produce output (16, 24 or 32-bit). Hauptwerk automatically uses the highest resolution supported by the interface and its driver.
- The virtual instruments that can be used, by way of its maximum sample rate. Hauptwerk will currently only allow an instrument to be used if the audio interface supports the sample rate used for its samples (technically speaking, that's in order to avoid the overheads of real-time anti-aliasing filters). Most recent virtual instruments require 48 kHz, although St. Anne's can be used at 44.1 kHz.

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 often 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, or perhaps two stereo pairs (for 'front' and 'rear' surround-sound amplification), might be preferred. (Multi-channel audio output facilities are only available in the Advanced Edition of Hauptwerk.)

Mac OS X has high-performance professional-grade audio built in ('Core Audio'), so there's much less dependence 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. Even the built-in audio outputs on Macs can be used reliably, with high performance, and with reasonable quality (although dedicated professional audio interfaces are likely to give higher quality).

On the Windows platform, the audio interface, and the quality of its driver, are the biggest factors determining the lowest latency that can be achieved and resilience to audio glitches. They also have a huge effect on achievable polyphony. ASIO drivers will usually give a much lower latency than DirectSound drivers, and good manufacturer-supplied ASIO drivers are usually much more resilient to audio glitches. If you want high polyphony, low latency, and reliable glitch-free audio on Windows, then *please buy a good 'pro' or 'semi-pro' audio interface* made by a company that genuinely specializes in good-quality professional/semi-professional recording studio products (such as some of those companies that we list in the '*Hauptwerk prerequisites*' section in the main Hauptwerk user guide), rather than economizing on the most important part of the whole system! A built-in PC audio output, or a consumer sound interface (such as those built by generic computer hardware companies, which are usually designed primarily for computer games and home multi-media use), or third-party/emulated drivers, will not usually give acceptable performance or quality for real-time, low-latency 'pro-audio' applications like Hauptwerk. On Windows, *a good pro/semi-pro audio interface should be considered a basic essential requirement* for any serious audio/MIDI/music purposes, including Hauptwerk. It's impossible to stress this point enough!

On the Windows platform, if getting a pro/semi-pro audio interface really isn't feasible for you at the moment, then the third-party ASIO4All driver (http://www.asio4all.com/) *might* make it possible to get acceptable performance (and resilience to audio glitches) from generic/consumer PC hardware sound outputs/interfaces, as a temporary measure. It often gives better results than DirectSound drivers. However, it still depends on the manufacturers' drivers and hardware to some extent, and success isn't guaranteed. It isn't a long-term substitute for getting a genuine pro/semi-pro audio interface!

Since the performance of any computer hardware, and the ability to use it with new operating system versions, depends upon its drivers, we recommend getting audio/MIDI interface models that are current and fully-supported by their manufacturers on the latest operating systems. Models that have been introduced fairly recently are likely to have the longest useful lifespans, in terms of future support from their manufacturers, and thus compatibility with other future computer hardware and operating systems.

USB and FireWire audio/interfaces tend to be more popular currently than PCI or PCIe ones, mainly due to the general trends towards portable computers above desktop computers. Some audio interfaces support both FireWire and USB, which can be beneficial in terms of 'future-proofing' (in case your current computer has FireWire ports, but you subsequently get a different computer which only has USB ports, for example), and in case you find that your computer has any compatibility or performance issues with one type of interface or the other.

We use, and particularly recommend, RME's (http://www.rme-audio.de/en_index.php) audio interfaces, since we've found their hardware, drivers, compatibility, support, quality and reliability all to be extremely good. However, there are plenty of other excellent manufacturers of audio pro/semi-pro interfaces.

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MIDI interfaces

If you want to play or control Hauptwerk in real-time then you need some form of MIDI interface (or a USB music keyboard) for the computer. Hauptwerk receives MIDI input to control its keys and its other virtual console controls, and it optionally produces MIDI output to drive external MIDI console hardware, such as solenoid-actuated or illuminated draw-knobs or tabs, LCD panels, or real external ranks of pipes.

(If you only intend to use Hauptwerk with a MIDI sequencer, or by clicking on its virtual keys on the screen, then you don't necessarily need a hardware MIDI interface.)

Many audio interfaces, have one or more MIDI input and MIDI output ports built in.

However, if you want to connect several MIDI input devices to Hauptwerk, such as several MIDI keyboards and/or MIDI draw-knob encoders, then you will usually need either a multi-port MIDI interface or a MIDI merge box, or to chain the devices together (if they allow that). Multi-port MIDI interfaces are highly preferable because their timing is usually more accurate and they are less easily 'flooded' by large/rapid amounts of MIDI data. (MIDI is a fairly old and slow protocol, with low bandwidth.)

In theory, 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 reliability. The MIDI standard doesn't officially support MIDI input devices being 'chained', although some MIDI hardware does support that as an extension to the standard (but using separate MIDI IN ports on a multi-port MIDI interface is still preferable for best performance, reliability, and minimum latency).

The amount of internal buffering a MIDI interface has (within its hardware, and/or within its driver) is very important because it determines its resilience to occasional 'lost' MIDI messages (which commonly most noticeably result in virtual keys 'sticking on' within Hauptwerk) in times of heavy MIDI traffic, and/or heavy CPU load. Insufficient buffering may also cause Hauptwerk to respond sluggishly, or cause registrations to get 'out of sync.' with a MIDI console. Plenty of MIDI buffering is essential if you plan to use large/complex virtual instruments, or large/complex MIDI consoles, or to use MIDI output from Hauptwerk (especially with LCD panels), or if you plan to perform in public (for which reliability is critical).

For those reasons we strongly recommend using good-quality 'pro' or 'semi-pro' MIDI interfaces, rather than budget 'micro' USB-MIDI adapters (which often have insufficient buffering). If you have multiple MIDI devices to connect, then we recommend choosing a multi-port MIDI interface, rather than 'chaining' MIDI devices. Buy a good-quality pro/semi-pro interface that has at least as many MIDI input ports as you have MIDI input devices to connect, and at least as many MIDI output ports as output devices that you have to connect.

Many recent music devices (especially music keyboards) can connect directly to a computer via USB ports, rather than via MIDI leads. Their drivers present the devices as virtual MIDI ports to MIDI applications such as Hauptwerk. Sufficient buffering is just as important for such devices. If you experience a buffering problem (such as stuck notes, sluggish response, or erratic behavior) when using a direct USB connection, then you could try connecting such devices via physical MIDI leads to a good-quality MIDI interface instead (assuming your USB music device has physical MIDI ports too).

Hauptwerk identifies MIDI ports by the names that the operating system reports for them (which in turn are determined by their drivers and/or the operating system). It isn't possible for Hauptwerk to keep track of the individual USB port to which any given USB-MIDI interface is attached.

On Windows platforms, if you have multiple identical USB-MIDI devices attached to the computer, and/or if you move a USB-MIDI device from one USB port to another, and/or you apply Windows or driver updates, then (depending on Windows and the USB-MIDI driver) its driver might possibly assign a different name to it, causing Hauptwerk to see it as a new/different MIDI device. Since Hauptwerk stores its MIDI settings relative to the MIDI ports they relate to, that might in turn cause your previous MIDI settings to be invalidated, in which case they might all need to configured (auto-detected) again from scratch (which can involve a lot of work). To try to avoid that, if you have multiple USB-MIDI devices, then you might wish to connect them all to a single, good-quality, ***powered*** USB hub and to ensure that you don't disconnect them from it. Doing so usually prevents Windows from re-ordering the USB ports, and prevents the drivers from assigning different port names to devices. Alternatively, connect all devices via physical MIDI leads to ports on a multi-port MDI interface, instead of connecting directly via USB.

Note that insufficient power supply to USB devices (and/or to USB hubs) is a common cause of strange/erratic behavior with USB-MIDI devices. If a USB-MIDI device has a power supply input, then you should use it. Similarly, we also recommend avoiding un-powered (a.k.a. 'bus powered') USB hubs, and low-budget USB hubs.

Not also that Hauptwerk doesn't currently support 'hot-plugging' of MIDI devices (or USB-MIDI devices). Hauptwerk queries the list of MIDI ports from the operating system when Hauptwerk launches. Always avoid unplugging MIDI/USB-MIDI devices while Hauptwerk is actually running.

As with audio interfaces, since the performance of any computer hardware, and the ability to use it with new operating system versions, depends upon its drivers, we recommend getting audio/MIDI interface models that are current and fully-supported by their manufacturers on the latest operating systems. Models that have been introduced fairly recently are likely to have the longest useful lifespans, in terms of future support from their manufacturers, and thus compatibility with other future computer hardware and operating systems.

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Storage drives (hard-disks and solid-state/SSD drives)

The speed of your computer's storage drives only determines the time it will take Hauptwerk to load a virtual instrument into RAM; real-time performance shouldn't be affected once the virtual instrument is loaded into RAM. SSD drives or RAID 5 disk arrays can be used if you want virtual instruments to load quickly (RAID 5, RAID 1 or RAID 0+1 can also make your system more resilient to the failure of a hard disk).

If you consider loading times to be important, then we recommend you use the fastest drive(s) available for your hardware, such as SSD drives or 7,200 or 10,000 RPM conventional hard-drives or RAID 5 arrays. SSDs are usually *much* faster than conventional hard-drives, but aren't yet available in sizes that are quite as large as conventional hard-drives.

'Hybrid' drives (which contain both a small SSD as a 'cache', and a conventional hard-drive for their main storage) are unlikely to offer any significant benefits for Hauptwerk purposes, since their SSDs aren't usually large enough to be used for loading virtual instruments, and so they're unlikely to perform any better than their conventional hard-drives alone.

Hauptwerk requires a large amount of disk space to allow for installation of virtual instruments, and also for cached instrument data. The cached data are used to speed up loading of instruments, and typically occupy very approximately an additional 50-100% of the amount of disk space occupied by the raw instrument data alone. Hence almost twice as much disk space as the raw instrument installation data alone may be required in total.

When installing Hauptwerk you can choose to put different parts of your Hauptwerk installation onto different drives. Consult the '*Installation: Background information: Planning installation locations*' section in the main Hauptwerk user guide for details. Hauptwerk users commonly choose to install two drives in their computers: one very large 7200 RPM hard-drive and one (fairly large) SSD, installing the operating system onto the SSD, as well as all Hauptwerk components, except for the '*Sample sets and components*' Hauptwerk installation folder which is instead installed onto the conventional hard-drive. That may be a good choice (being more cost-effective than using SSDs for everything) because the contents of the '*Sample sets and components*' installation folder may be extremely large (if you install a lot of virtual instruments) but they only change occasionally (when you install or load new components for the first time) and they don't significantly affect virtual instrument loading times.

For example, you might choose to install a 512 GB SSD in a computer as the main drive, along with a 2 TB 7200 RPM conventional hard-drive for the Hauptwerk '*Sample sets and components*' installation folder.

Note that it isn't currently possible to install just a subset of your virtual instruments onto one drive (an SSD, for example), whilst installing others onto another drive (a conventional hard-drive, for example). Hence you need to ensure that the drive(s) you buy are large enough for all of the virtual instruments you plan to install. It's possible to re-run Hauptwerk's installer to change installation locations in the future. Hence if you subsequently discover that your hard-drive isn't large enough then you would need to get a new, larger, one, then use the installer to move your existing installation (or parts of it) to it. However, you couldn't simply add a new drive and use it only for virtual instruments installed subsequently, whilst keeping the previous ones on your old drive.

For installation in an environment where absolute reliability is critical, such as for public performance, two or more matching drives in a RAID 5, RAID 1, or RAID 0+1 array are recommended, since they should tolerate the loss of any one drive without losing any data.

Computer hardware lifespan, evolution and maintenance

Computer technology evolves very rapidly. 'Moore's Law' effectively states that the computing power that will be available in new computers is likely to double every 18-24 months. Hence if you spend a certain amount of money on a computer now, and then spend about the same amount on a new computer in two years' time, the later computer will probably have about twice as much CPU power and about twice as much RAM as the current one (even though it would cost the same amount of money).

New versions of computer software applications, including new operating systems, hardware drivers, new versions of Hauptwerk, and new virtual instruments available for it, are likely to take advantage of those advances in available computing power and RAM to make Hauptwerk and virtual instruments more realistic. For example, 'surround' (2x 2-channel) virtual instruments are popular now because most recent computers have sufficient processing power and RAM for them, whereas previously most virtual instruments were stereo (2-channel).

Hence even if you buy a computer that can handle all of the existing virtual instruments that you want to use now, it's likely that future virtual instruments (and/or future Hauptwerk versions) will eventually become available that will be able to benefit from even more computing power and RAM than your computer has.

The useful and working lifespan of computer hardware is typically only about 3-5 years. You should thus plan, and budget, for replacing your computer hardware every 3-5 years. Even if your computer still works in 5 years' time then there's a good chance that the versions of the operating systems, hardware drivers, and applications that are current and available then won't be able to run on it. That's the nature of computer technology: it evolves very rapidly and becomes obsolete rapidly. We try very hard to keep Hauptwerk backwardly-compatible with older operating systems and computer hardware as long as we can, but that isn't possible indefinitely (since new versions of Hauptwerk need to support new operating systems as well).

If you buy a newly-released piece of hardware (for example an audio/MIDI interface), or operating system, or software application, then it's likely only to work on hardware and operating systems that were released within about the last 3-5 years. Computer hardware, operating systems, drivers and software need to be kept reasonably up-to-date since they all depend upon each other. Especially if your computer is

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connected to the Internet then it's also very important to make sure that its operating system is updated regularly, and that it has up-to-date virus scanning and firewall software to try to ensure that it remains secure.

At any given time the most powerful computers available are usually *much* more expensive than computers that are only a little less powerful than them. However, as Moore's Law implies, even if you bought the highest-performance computer available now (which is likely to be extremely expensive), then in two years time it will probably easily be out-performed by standard mid-priced computers available at that time. Your (extremely expensive) computer might only have a lifespan of 3 years anyway. Even if it did still function after 3 years, since it had cost so much, you might feel reluctant to replace your computer then, so you would be stuck with a system that was (by then) relatively obsolete and relatively low in performance, compared to the standard computers of the time.

It thus often makes sense to buy computer hardware that is absolutely current (so that it takes advantage of the latest advances in technology and has the longest possible useful lifespan), and that is reasonably high-performance, but that isn't the very highest-performance hardware available, then plan to replace it regularly (about every 3 years). That way you can remain fairly close to the 'cutting edge' in terms of performance, without excessive cost overall.

Buying second-hand computer hardware is usually only worth considering if it's hardware that was made very recently, otherwise it may soon be obsolete (no longer supported by operating system makers, hardware makers' drivers and applications, and/or its hardware may no longer be compatible with current devices), and/or it may reach the end of its working life sooner.

Computers need some periodic maintenance too: operating system updates need to be applied, software applications need updating regularly, they need backing up regularly, and hardware needs checking and replacing periodically. (Especially if installing a computer in a permanent Hauptwerk installation, such as in a concert hall) then it's important to plan and budget for such maintenance, replacement and upgrades, both financially, and in terms of ensuring that somebody with sufficient computer experience is available to perform it.

The second-hand value of computer hardware is usually relatively low, unless the hardware is recent/current (again because older hardware is likely to have a short remaining useful/working lifespan).

Types of computers

Broadly, current 'home' computers can be classified into:

- *Desktop computers.* These are usually the most cost-effective, and tend to be flexible and upgradeable (to some extent).
- *Portable/laptop/notebook computers*. These are convenient and portable, but they usually cost more than desktops for a given specification, they usually aren't as upgradeable, and their lifespans are often a little shorter (since their hardware is miniaturized and tends to run hotter).
- *Servers/workstations*. These are the most powerful and expensive, designed for intensive professional applications.
- *Tablets, smart-phones and other devices.* These are still usually much less powerful than the other types and Hauptwerk can't currently run on them (unless they run a standard, non-RT, version of Windows and are specifically designed to run standard Windows applications).

Hauptwerk is available for both Macs and PCs. Macs usually work and perform very well for 'pro-audio/MIDI' (low-latency, real-time, CPU-intensive) applications such as Hauptwerk 'out of the box', whereas Windows/PCs might (or might not) require some technical expertise and tweaking in order to achieve and maintain that. If you don't have much technical computer experience or inclination then we recommend either buying a Mac or buying a PC from a company that builds, maintains and supports them specifically for Hauptwerk (or for general 'pro-audio/MIDI') purposes. In a PC the ability to achieve reliable (glitch-free) real-time, low-latency audio, high polyphony, and reliable MIDI performance, depends heavily on the specific combination of hardware components and drivers within the PC (and especially the audio/MIDI interface hardware/drivers), whereas Mac OS X has high-performance professional-grade audio and MIDI drivers built in, so there's much less dependence on hardware or driver quality on OS X. Also Macs, including OS X, are designed and tested specifically for those purposes as complete units by their manufacturer, whereas generic off-the-shelf PCs usually aren't. On PCs the hardware, operating system and drivers are usually manufactured by different companies. However, PC hardware is often cheaper and there is more choice.

Since we (Milan Digital Audio) don't make or sell computer hardware, and since such hardware evolves so frequently, and since the only way to be certain of performance and compatibility with any given combination of PC components, unfortunately it isn't feasible for us to offer any significant help with using, building or troubleshooting computer hardware, drivers or operating systems, beyond the advice given in this document and in the main Hauptwerk user guide.

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