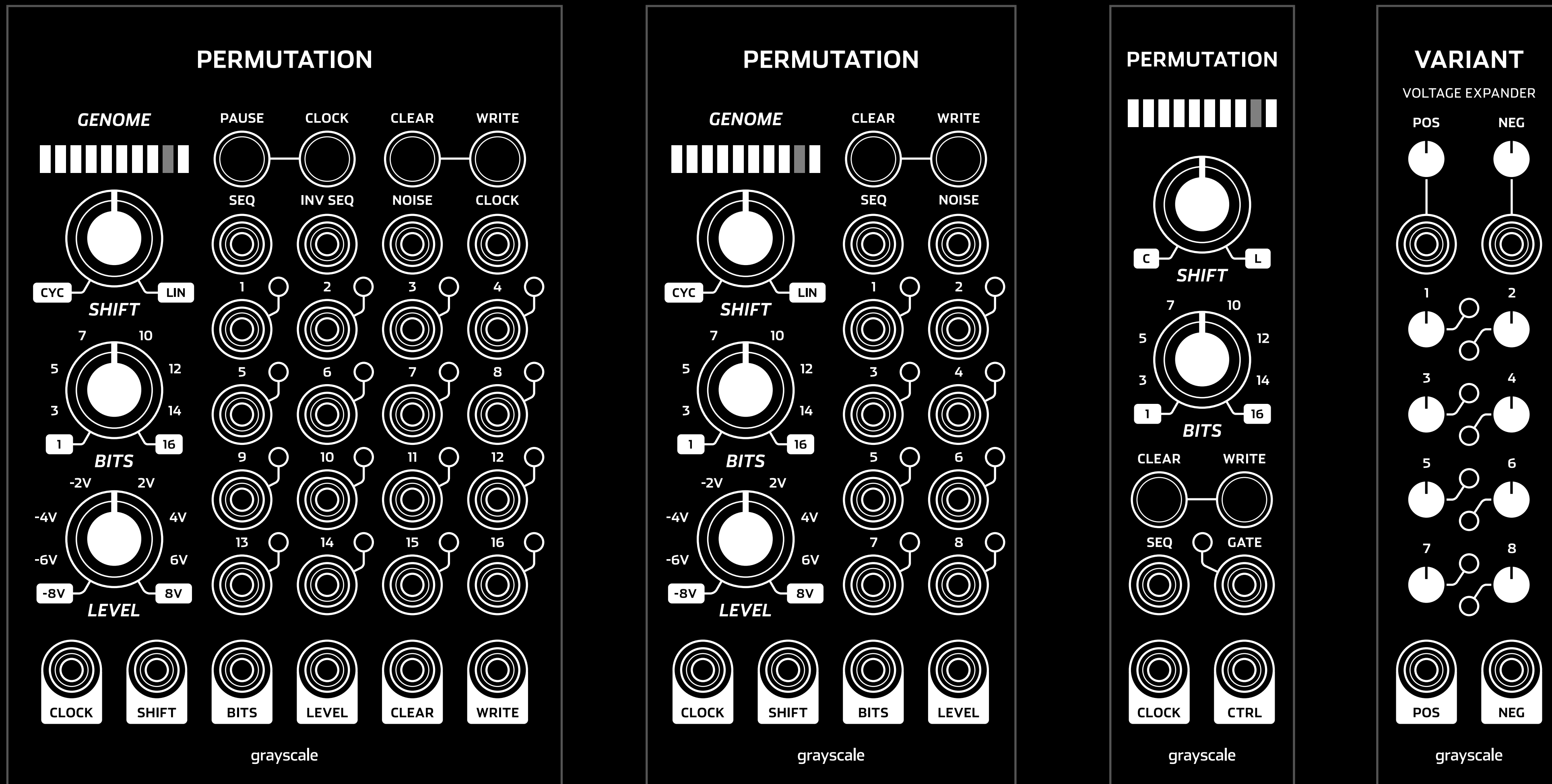

GRAYSCALE

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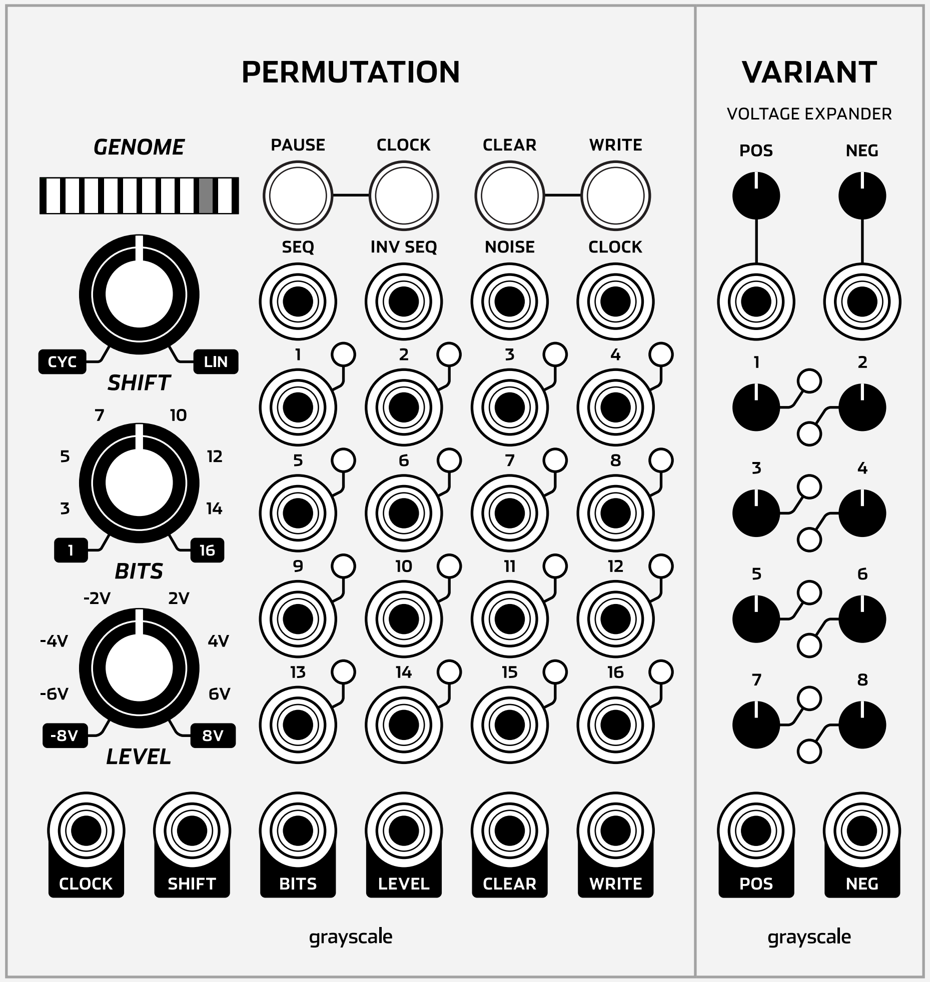


Welcome to the Machine

Permutation is a random looping sequencer that uses a linear feedback shift register (LFSR) as the basis for generating unpredictable CV and gate patterns.

It is a direct descendant of the Turing Machine, an open source module designed by Tom Whitwell of Music Thing Modular. The TM itself was inspired by classic random signal generation units such as the Buchla Model 266 (Source of Uncertainty), the Wiard Model 1210 (Noise Ring), and the Triadex Muse (an obscure device invented by artificial intelligence researchers at MIT in the 1970s).

Permutation retains the core functionality of the Turing Machine and its Pulses expander while adding new features in a more compact interface. Variant, a compact 6hp expander module that provides a secondary means of generating correlated random sequences, is based on the original Voltages expander for the Turing Machine.

Feature	18hp	12hp	6hp
Sequence CV output	●	●	●
Inverted sequence CV output	●	×	×
Clock output	●	●	×
Gate outputs	16	8	1
Bipolar VCA	●	●	Optional
Pause/Clock switches	●	×	×
Clear/Write switches	●	●	●
Clear/Write CV inputs	●	×	×
+12V current draw*	48 mA	48 mA	48 mA
-12V current draw*	14 mA	14 mA	14 mA

* Note that Variant receives its power supply from Permutation, so attaching the expander increases the current draw of Permutation by 23 mA on the +12V rail and 20 mA on the -12V rail for a total of 71 mA and 68 mA respectively.

Operational Theory

Permutation generates two types of random sequences: trigger/gate sequences based on a series of binary values (zeroes and ones) and a control voltage sequence that is calculated based on the first eight bits of the shift register.

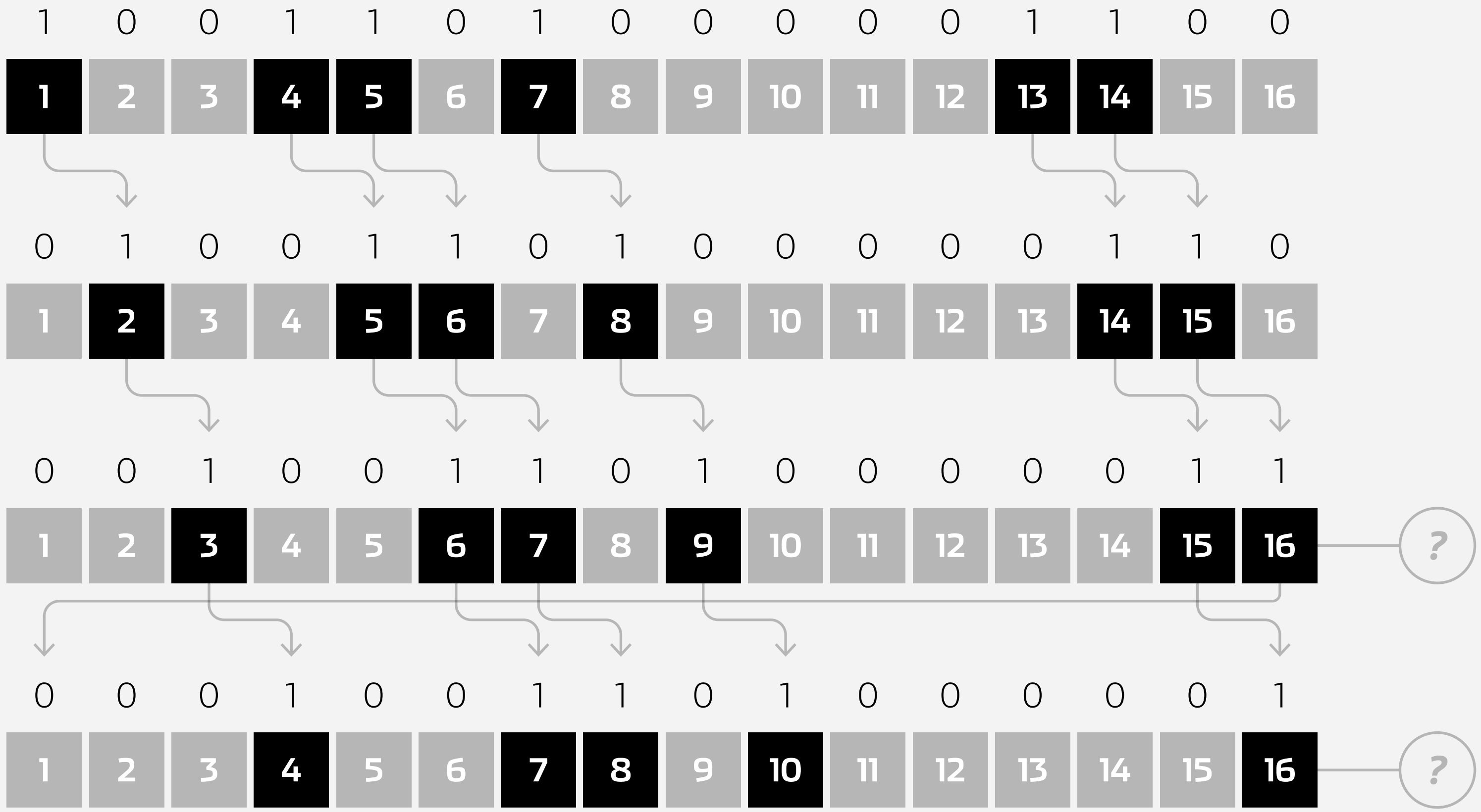
Consider a trigger/gate sequencer like the Grayscale Algorhythm where you can program a specific pattern with a length of up to 64 steps. A clock pulse advances through each step of the pattern and repeats once the last step is reached. When a step is "off" it's equivalent to a binary value of 0 (zero). When a step is "on" it's equivalent to a binary value of 1 (one). So a trigger sequence is basically just a binary sequence of zeroes and ones as well, but each step has a fixed binary value controlled by the user.

Permutation works a bit differently. With each clock pulse, the binary sequence itself is copied from one step to the next. The value of Bit #1 is copied to Bit #2, which is then copied to Bit #3, etc until the binary sequence reaches the last active bit (determined by the BITS knob). As the value of the last bit is copied back to Bit #1, there's a possibility that the value will change states (0 to 1, or 1 to 0) because there is a degree of user-controlled entropy involved in the copying process.

This entropy is determined by the SHIFT knob and CV input (which sets the level of a comparator) and the internal analog white noise generator (which is sampled and compared against the SHIFT level, determining the outcome of this stochastic process). By the time a binary sequence passes through the entire shift register, it could be completely different… or only slightly different… or it could remain unchanged.

The result depends on the position of the SHIFT knob. In the center position the binary sequence has a 50/50 chance of changing states (0 to 1 or 1 to 0). As you turn the SHIFT knob to the left or right, the "entropy" of the copying process is reduced. At the farthest left or right positions, there is no entropy because the last bit is always copied to the first bit with 100% accuracy. This means that the sequence is no longer being randomized. Both the binary sequence and the CV sequence will be locked into repeating loops instead of being "mutated" over time.

The 18hp version of Permutation lets you tap into each bit of the shift register, which is a powerful technique for generating identical time-shifted patterns used in musical counterpoint, rounds, and canons.



Although these diagrams show 16 active bits, the concept is the same for all sequence lengths. The BITS knob simply determines the last bit in the sequence, which is the point at which a binary value is copied back to the first bit and potentially randomized. This value also sets the loop point for locked sequences.

The last binary value in the sequence may or may not be inverted once it's copied back to the first bit. The SHIFT knob controls the probability of this change occurring.

Now the last bit has another chance of being flipped as it's copied back to the first bit.

These diagrams represent the 16 bits of the shift register. Why are they called bits and not steps like other sequencers? Because a shift register is not really a sequencer… it's a primitive analog form of data storage. Each bit in the shift register can be a zero or a one. By converting these bits to control voltages, a trigger/gate sequence is generated: zeroes correlate to 0V and ones correlate to +10V pulses on the Permutation gate outputs.

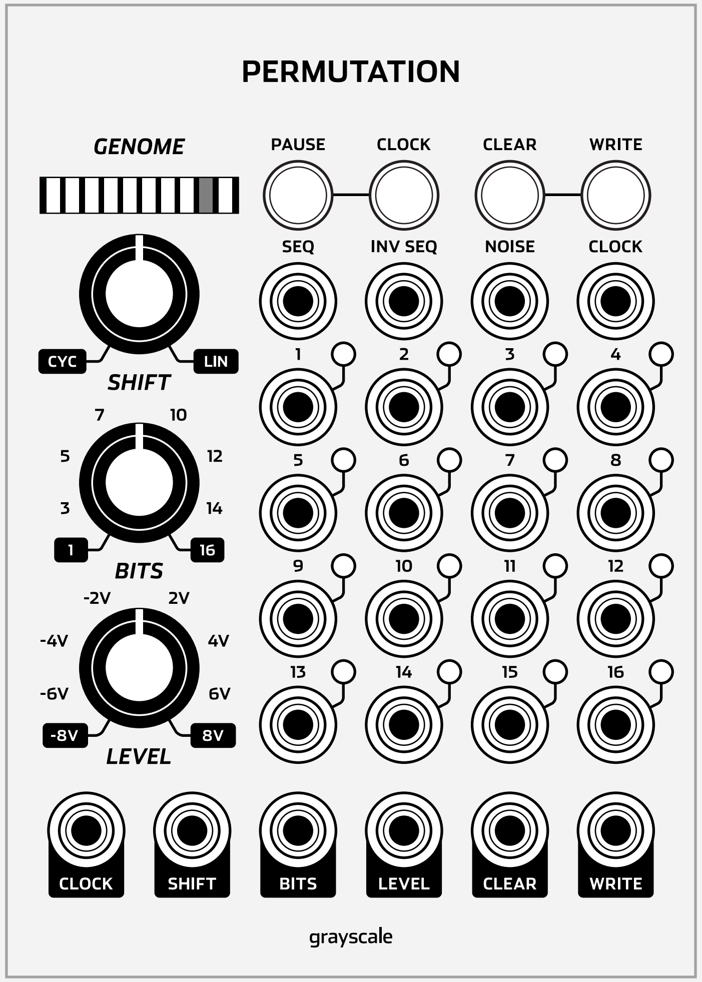
The diagrams above show a 16-step sequence. When a value is passed to the last bit (Bit #16 above), it's copied back to Bit #1 but the value might be flipped. In the last diagram, note that Bit #1 has a zero value – the randomization process inverted the one and it's now a zero. The binary sequence and the random CV sequence have changed, and this change will be passed down the line until the end, where randomization may occur.

The random CV sequence is generated by evaluating the first eight bits of the shift register and calculating their value as an 8-bit "byte" (a basic concept of digital computation). Each bit has one of two states, and there are eight bits, so the output range is **`2^8=256`** discrete values.

The voltage at the SEQ output can be calculated as:

`(8-bit byte / 256) * LEVEL = SEQ`

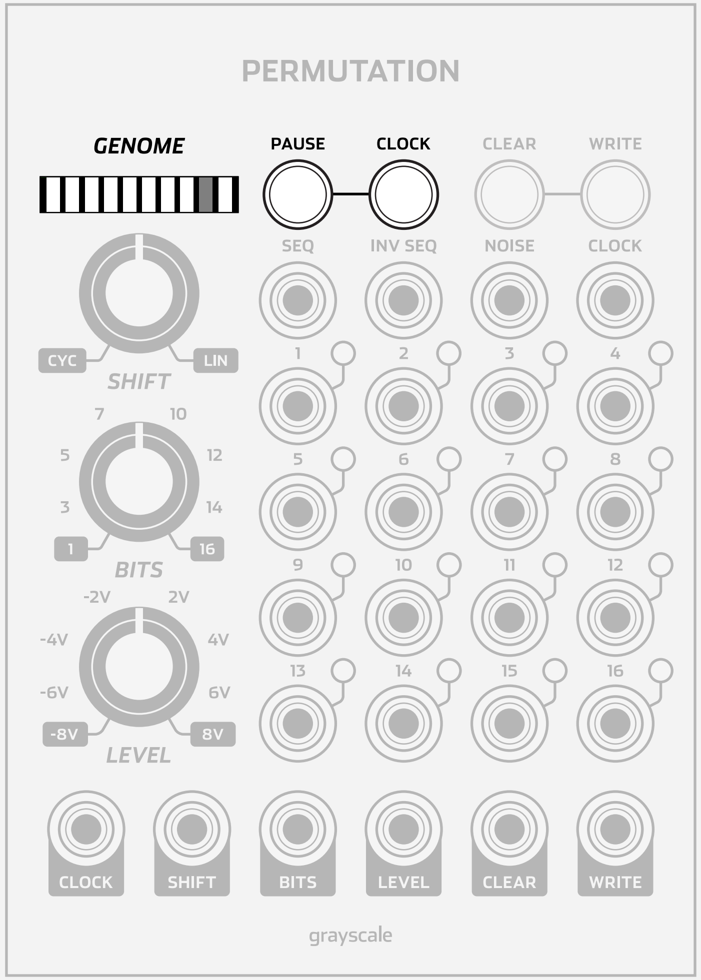
Looking at the last diagram above, the raw 8-bit value of **`00010011`** can also be calculated as an 8-bit byte of **`8+6+128=200`** because the numbers 8, 64, and 128 map to the bits that have a value of 1. Bits with a value of 0 aren't calculated as part of the byte. With LEVEL set to +8V the final SEQ output voltage is: **`(200/256)*8 = +6.25V`** (Note that because of analog tolerances in the output circuitry this is an approximate value, not absolute.)



PERMUTATION 18hp

The operational theory of Permutation may seem complex but the more you work with the module, the more clear its underlying logic will become.

The specific features of each version of Permutation will now be explored. We'll begin with the 18hp version, which is the most powerful module in the lineup and includes all features of the smaller versions.



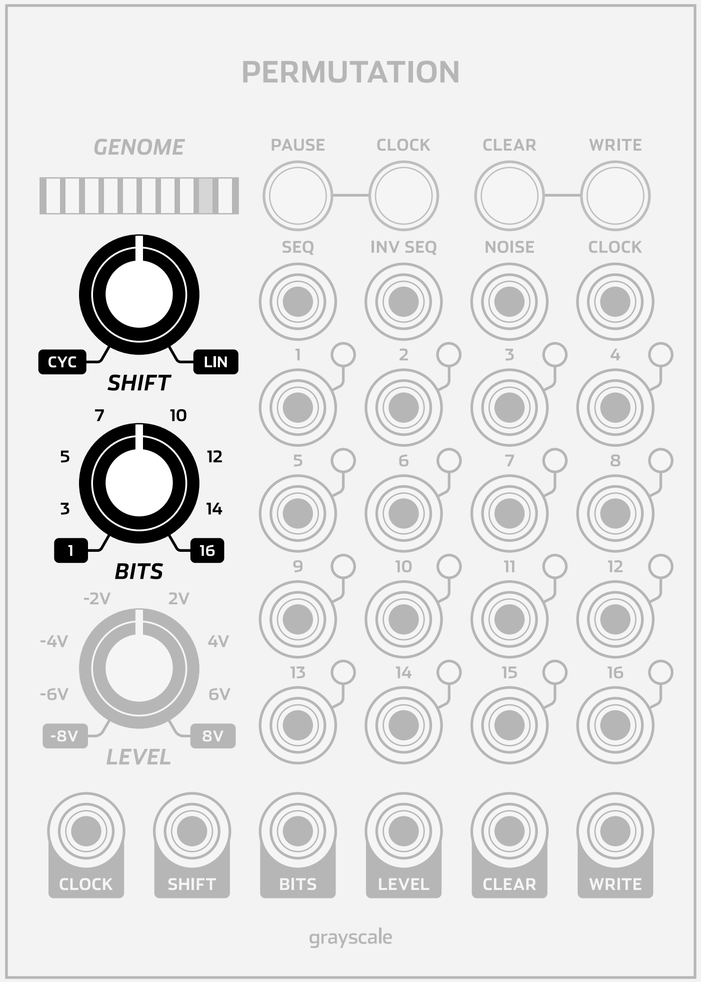
GENOME Display

LEDs #1-8 show the contents of the first eight bits of the shift register. LEDs are illuminated when the bit is currently high (i.e. when its binary value = 1) and dark when the bit is low (binary value = 0). LED #9 is currently unused (always dimmed). LED #10 is illuminated when the clock input signal is high.

PAUSE/CLOCK Switches

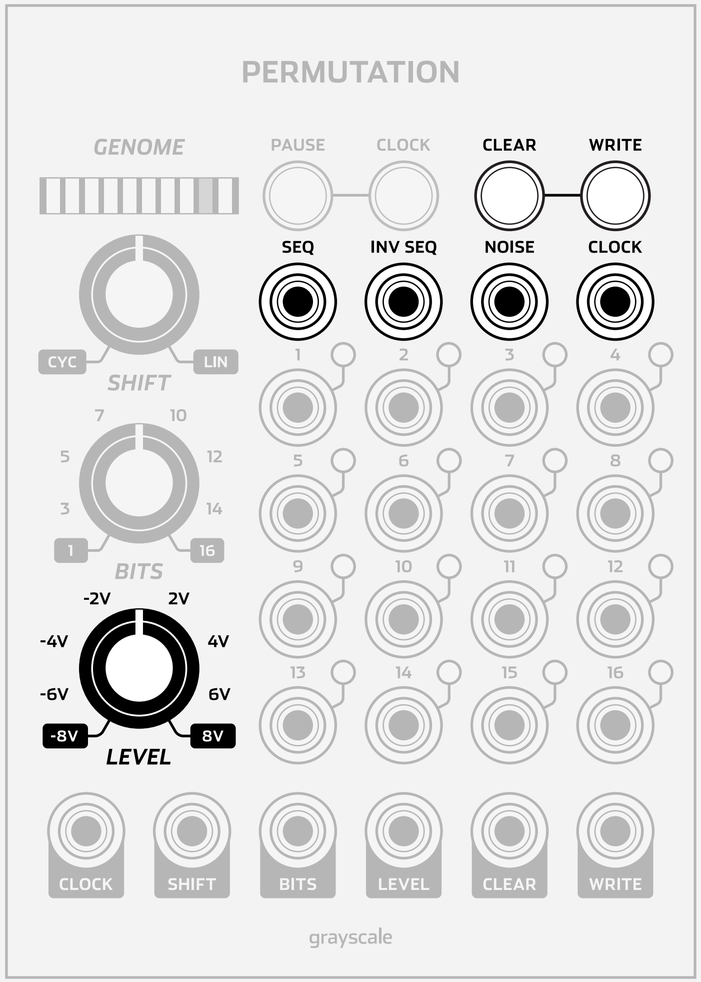
These two momentary switches effectively shift a sequence backwards or forwards in time. When PAUSE is being pressed, the clock input will be disconnected and the sequence will stop. Release PAUSE when you want to resume playback. Pressing CLOCK will generate an internal pulse that steps the sequence forward by one step (assuming that the clock input is not already high). These functions are particularly useful when aligning a locked random sequence with other timing events in a patch.

SHIFT and BITS Knobs



Permutation has a mind of its own but it can be subtly manipulated or locked into repeating patterns. The SHIFT knob controls how random each repetition of the sequence will be. With the pointer at the center position, the sequence is completely random. Turning the knob to the right will decrease the degree of entropy. At the LIN (linear) position the sequence will lock into a repeating loop with a length equal to the value of the BITS knob.

Turning SHIFT to the left will also decrease the degree of entropy, but once the sequence reaches the last bit (which is determined by the BITS knob), the binary sequence will be inverted for one repetition of the loop and then inverted again for the next repetition. This creates a pendulum or "Möbius strip" effect for the binary sequence and the CV sequence. At the CYC (cycle) knob position this Möbius sequence (forward, reverse, forward, etc) will be repeated infinitely. Its length is 2x the BITS value (up to 32 steps).

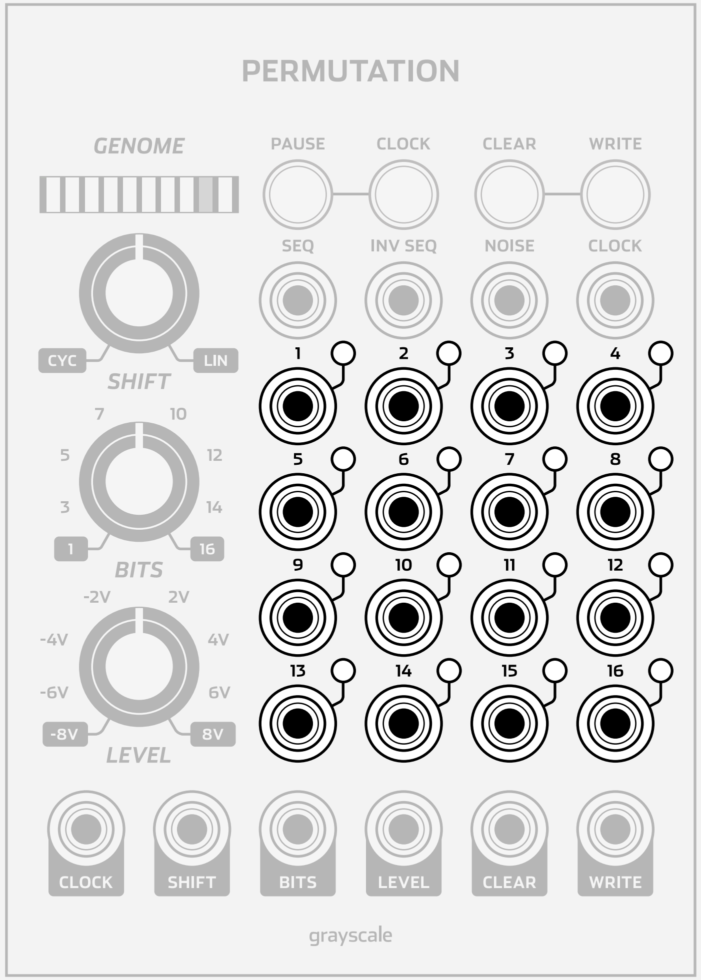


CLEAR/WRITE Switches

These switches modify the current binary sequence. Hold CLEAR to change ones to zeroes, hold WRITE to change zeroes to ones. This inversion is applied to the current value of Bit #1 when the clock source is high. If you want to use the CLOCK switch to step through each bit, hold CLEAR or WRITE before tapping CLOCK, because a clear/write command must be received before the clock goes high. The same logic applies when using an external clock source.

LEVEL Knob and CV/signal outputs

The LEVEL knob controls a bipolar VCA which determines the output range of SEQ (sequence) and INV SEQ (inverted sequence). If SEQ is generating a positive CV, INV SEQ will generate a negative CV, and vice versa. NOISE provides access to the analog white noise generator, calibrated for a 10Vpp AC output level. The CLOCK output is simply a regenerated copy of the CLOCK input on the bottom left.

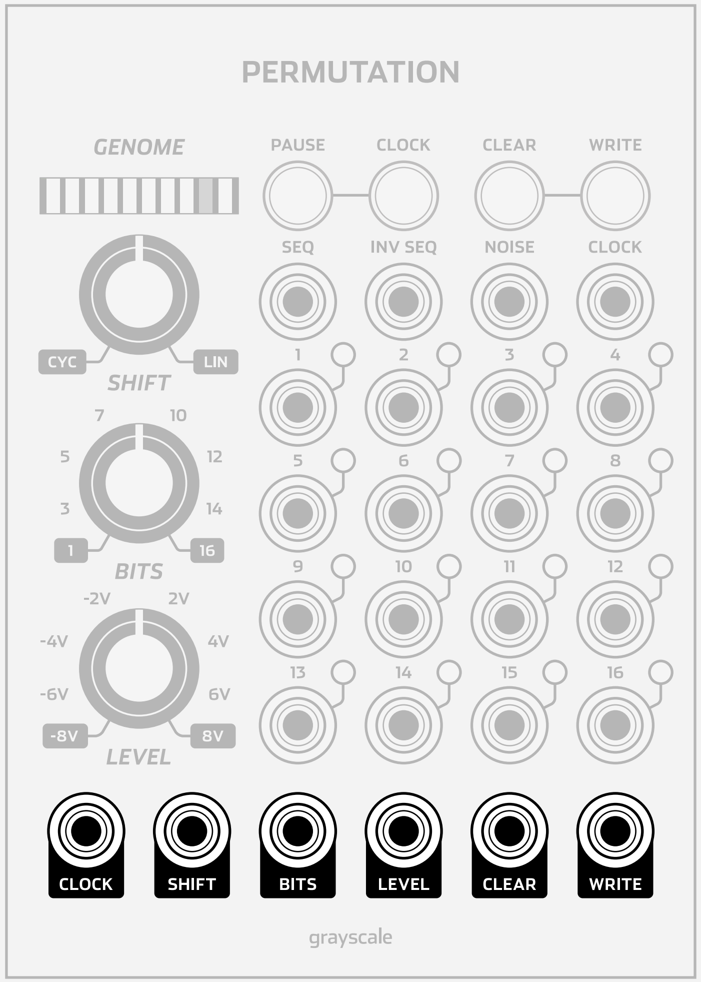


BINARY Outputs

These 16 outputs are correlated with the 16 bits of the shift register. When their respective bits in the shift register are high, each output will generate a +10V pulse and its corresponding LED will illuminate. The pulse width of the outputs is determined by the pulse width of the CLOCK input. If you want the outputs to be short triggers, use a clock source that is also a short trigger.

Sequence Memory

Permutation adds a very useful feature not present on the Turing Machine: sequence memory. When the SHIFT knob is set to CYC or LIN, the current sequence will be memorized. The next time you power up your system, you can continue where you left off. If you want to start over from scratch, turn the SHIFT knob towards the center and the saved sequence will eventually be overwritten as the shift register values are randomized.

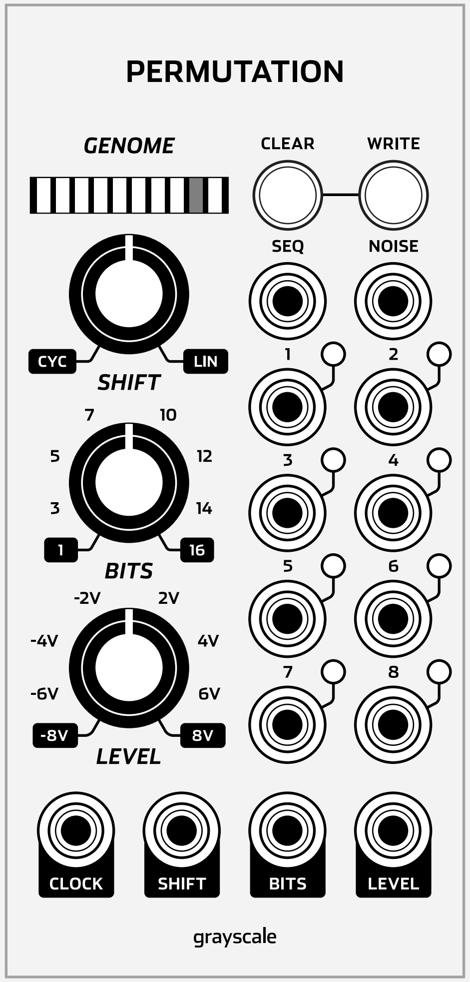


CV Inputs

A CLOCK source is required to advance the sequence. Pulse waves are expected, but other signals may also work. The CLOCK switch is combined with this input so if either clock source is already high, the other will have no effect.

The SHIFT, BITS, and LEVEL inputs are voltage offsets for the positions of their respective knobs, with a modulation range of -5V to +5V. Locking or unlocking a sequence using an LFO, modulating the sequence length using another sequencer, or transposing the SEQ outputs are just a few potential ways to use these inputs.

Like their corresponding switches, the CLEAR and WRITE inputs can be used to flip the value of Bit #1 in the shift register. These are logic inputs, so they accept positive voltages only (negative voltages will have no effect). Triggers, gates, envelopes, and unipolar LFOs are good modulation sources to use here.

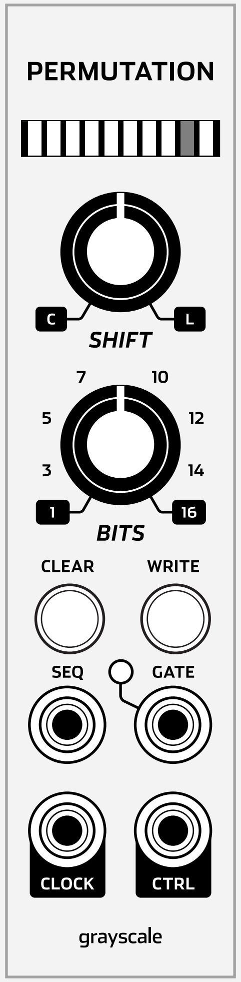


PERMUTATION 12hp

The 12hp version retains the core functionality of the 18hp version in a smaller size. To create a smaller module, the following features were excluded:

- PAUSE and CLOCK switches
- INV SEQ output
- CLOCK output
- Pulse outputs 9-16
- CLEAR/WRITE CV inputs

All other features function identically to the 18 hp version, with the same modulation ranges and output levels.

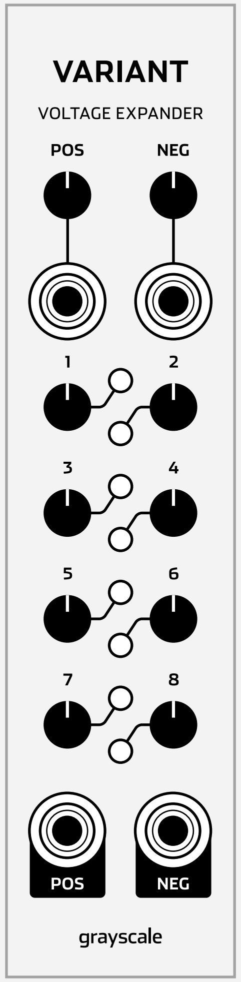


PERMUTATION 6hp

The 6hp version is the most minimal possible take on the concept. Compared to the 18hp version, it lacks the:

- PAUSE and CLOCK switches
- INV SEQ output
- NOISE output
- CLOCK output
- Pulse outputs 2-16
- CLEAR/WRITE CV inputs

The GATE output is mapped to Bit #1 of the shift register. The CTRL input can be assigned to SHIFT, BITS, or LEVEL. Hold the CLEAR and WRITE switches for three seconds to cycle through the modulation targets. LED #1 represents SHIFT, LED #2 represents BITS, and LED #3 represents LEVEL. The modulation range is +/-5V. Note that with CTRL assigned to LEVEL, the baseline voltage of the SEQ output will be 0V – an external CV input is expected.

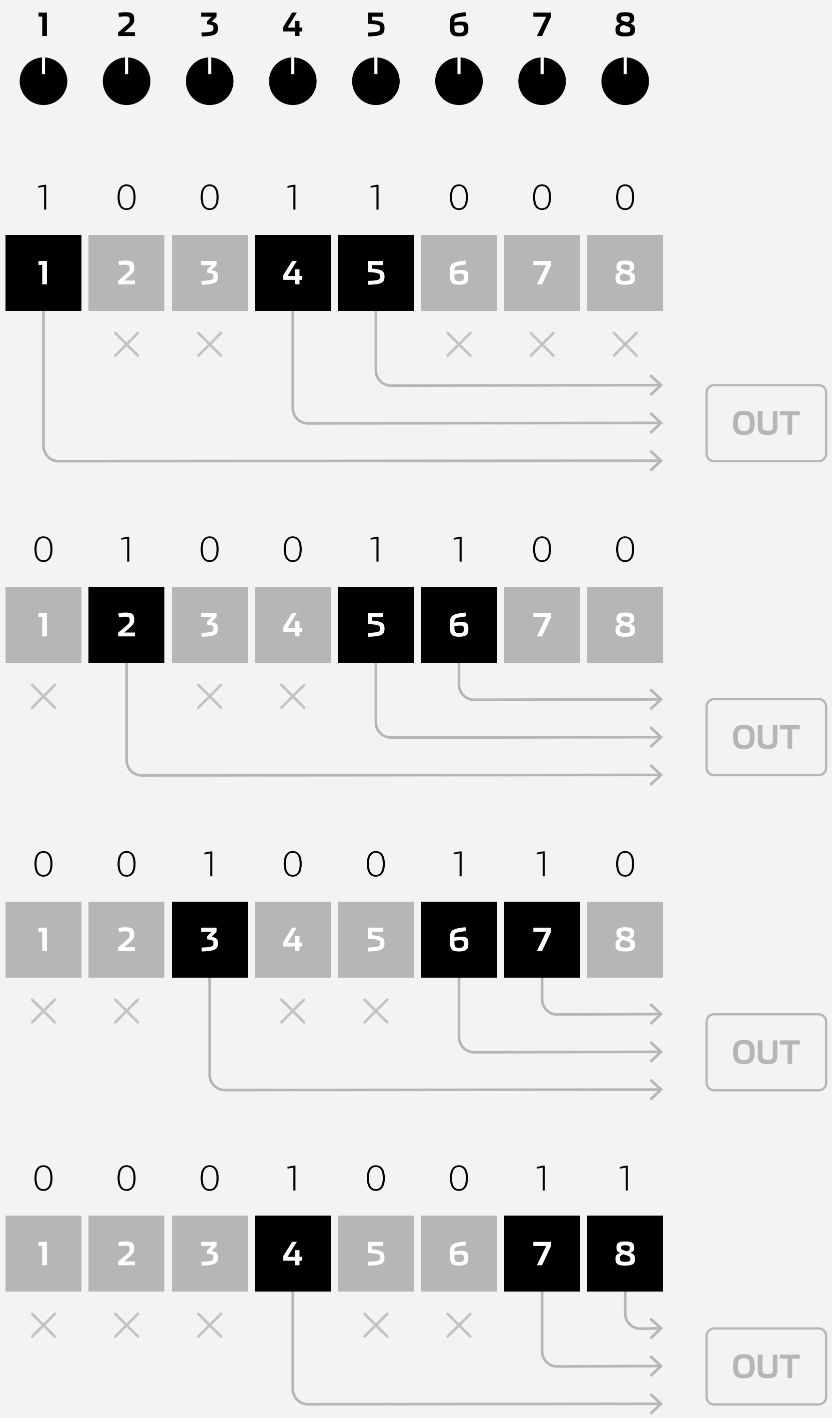


VARIANT Expander

Variant is a compact version of the original Voltages expander for the Turing Machine, with the added benefit of CV inputs to modulate the output levels (modulation range of -5V to +5V). Unlike Voltages, the POS and NEG outputs of Variant both have attenuators (on Voltages, the NEG output had an offset knob instead).

Variant connects to the GATES expansion header of Permutation using the supplied 16-pin to 16-pin ribbon cable and receives its power supply from the connected module. Note that the thick lines on the PCBs of both modules indicate proper cable connection (align the red stripe on both modules to the thick lines on the PCB).

Variant will work with either version of the Turing Machine but because the GATES header on Permutation is reversed compared to the Turing Machine, the bits are also reversed (8=1, 7=2, 6=3, etc). The functionality is otherwise identical.



Variant, like Voltages, is a "mixer" of sorts for the binary sequence of the connected Permutation module. The interface provides a different method of creating random voltages than the method used on Permutation itself.

The GATES header on Permutation sends the values of the shift register bits 1-8 to Variant. For each clock pulse that Permutation receives, Variant will receive a new set of eight binary values. These values will be passed down the line to each potentiometer, creating a dynamic mix of output voltages based on the knob positions. If the sequence on Permutation is locked (SHIFT knob set to CYC or LIN), the sequence on Variant will also be locked.

The diagrams to the left indicate that if a bit is high (binary value = 1) then the knob associated with that bit can be used to add a voltage with a range from 0V to 4.5V to the overall voltage mix. If a bit is low (binary value = 0) the knob contributes nothing to the mix even if it's turned fully clockwise, because its respective bit has no associated voltage to mix. The LEDs on Variant indicate whether a given bit is high or low (LED on = binary value of 1).

Each knob can contribute up to 4.5V to the mix, although the maximum voltage of the POS output is about +10V and the NEG output peaks at about -10V. The knobs use a roughly exponential scale, so the higher voltages are clustered towards the upper half of each knob's range.

Source files for Permutation and Variant will be shared once the costs of developing and manufacturing these modules have been recovered.

Thanks to Tom Whitwell of Music Thing Modular for making the Turing Machine available under this license and for approving the usage of his ideas and implementations in these new modules. Visit www.musicthing.co.uk to learn more about Tom's other DIY-oriented Eurorack projects.

The name "Permutation" itself refers to the fact that these modules build upon a lineage of random signal generators that date back to the 1970s. The patent images for the Triadex Muse (US Patent 3610801) include a reference to "Permutative Switching," which was only noticed once Permutation was already in production – it seems that history repeats itself in random ways.

GRAYSCALE

www.grayscale.info

Permutation + Variant

User Manual Revision 1.1