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Film Grain Technology — Specifications for H.264 | MPEG-4 AVC Bitstreams

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1.1 General

1.1.1 Scope

This document provides bit-accurate Film Grain Technology specifications for H.264 | MPEG-4 AVC bitstreams. Film grain simulation is an option for H.264 | MPEG-4 AVC video coding layer. These specifications make use of film grain characteristics Supplemental Enhancement Information (SEI) messages compliant with Annex D of the ITU-T Recommendation H.264 | ISO/IEC 14496-10 International Standard.

1.1.2 Normative References

[1] ITU-T Recommendation H.264 | ISO/IEC 14496-10:2005 International Standard

1.2 Technical Elements

1.2.1 Definitions

For the purposes of these specifications, the same terminology as in [1] will be used.

1.2.2 Abbreviations

IDR: Instantaneous Decoding Refresh
LSB: Least Significant Bit
LUT: Look Up Table
MSB: Most Significant Bit
POC: Picture Order Count
PRNG: Pseudo-Random Number Generator
SEI: Supplemental Enhancement Information

1.2.3 Mathematical functions

Clip(x, y, z) = x, if z < x;
y, if z > y;
z, otherwise

Mod(x, y) = x - y * Floor(x/y); defined only for integers x and y, with y > 0

Floor(x) = the greatest integer less than or equal to x

x % y = remainder of x divided by y; defined only for integers x and y, with x >= 0 and y > 0

1.3 Introduction

This document provides bit-accurate film grain technology specifications to add film grain to decoded frames from a H.264 | MPEG-4 AVC bitstream. Film grain simulation shall be performed after decoding the video bitstream and prior to frame display. The film grain simulation process requires the decoding of film grain characteristics SEI messages, conveyed in ITU-T Rec. H.264 | ISO/IEC 14496-10 bitstreams as specified by the Amendment 1 (Fidelity Range Extensions) [1].

Specifications affecting the film grain characteristics SEI message are provided to ensure the technology will meet the requirements of high definition systems in terms of quality and complexity.

1.4 Film grain characteristics SEI message specifications

The value of the parameters conveyed in an ITU-T Rec. H.264 | ISO/IEC 14496-10 film grain characteristics SEI message are constrained as follows:

model_id. It shall be 0, which identifies the film grain simulation model as frequency filtering.

separate_colour_description_present_flag. It shall be 0, which indicates that the color space for film grain simulation is the same as for encoding.

blending_mode_id. It shall be 0, which corresponds to the additive blending mode.

log2_scale_factor. It shall be in the range [2, 7] to ensure the film grain simulation can be performed using 16-bit signed integer arithmetic.

intensity_interval_lower_bound[c][i] and **intensity_interval_upper_bound[c][i]**. For all c and for any intensity value v, there shall be at most one intensity interval i that verifies **intensity_interval_lower_bound[c][i]** <= v and **intensity_interval_upper_bound[c][i]** >= v, since multi-generational film grain is not allowed.

num_model_values_minus1[c]. For all c, it shall be in the range [0, 2], which specifies that band-pass filtering and cross-color correlation are not supported.

comp_model_value[c][i][0]. For all c and i, it shall be in the range [0, 255] to ensure film grain simulation can be performed using 16-bit signed integer arithmetic.

comp_model_value[c][i][1]. For all c and i, it shall be in the range [2, 14], which includes all the required grain patterns.

comp_model_value[c][i][2]. For all c and i, it shall be in the range [2, 14], which includes all the required grain patterns.

film_grain_characteristics_repetition_period. It shall be equal to 0 to specify that the film grain characteristics SEI message applies to the current decoded frame only.

NOTE – All frames where film grain must be inserted shall be preceded by a film grain characteristics SEI message. This approach ensures bit accuracy in trick mode play, and allows bit-accurate film grain insertion in both decode order and display order.

Combining all the color components c and intensity intervals i in an SEI message, the number of different pairs (comp_model_value[c][i][1], comp_model_value[c][i][2]) shall be equal or smaller than 10.

NOTE – The previous constraint applies after scaling the chroma film grain model values, as specified in subclause 1.5.3.1.

All the other parameters in the film grain characteristics SEI message specified by the ITU-T Rec. H.264 | ISO/IEC 14496-10 standard have no constraint according to this specification.

The following film grain simulation method shall only be used on progressive content. In an H.264 | MPEG-4 AVC bitstream, this can be ensured by restricting the usage of these specifications to bitstreams where frame_mbs_only_flag equals 1.

1.5 Bit-accurate film grain simulation

Upon reception of a film grain characteristics SEI message, film grain simulation is performed in the current decoded frame unless film_grain_characteristics_cancel_flag is 1. If no film grain characteristics SEI message is received for the current decoded frame, then no film grain shall be simulated on the current decoded frame.

The simulation of film grain applies to all color components. Film grain is simulated and added to color component c if comp_model_present_flag[c] equals 1 in the film grain characteristics SEI message. Bit-accurate film grain simulation is accomplished by specifying: a database of film grain patterns; a uniform pseudo-random number generator; and a precise sequence of operations. Film grain can be simulated independently for each color component. Monochrome signals can only have grain on the luma component.

1.5.1 Database of film grain patterns

The database of film grain patterns derived from the present specifications is composed of 169 patterns of 4,096 film grain samples, each representing a 64×64 film grain image. The values in the database can be stored in 2's complement form and range from –127 to 127. The film grain pattern database shall be generated according to the method provided in subclause 2. Such method is a bit-accurate implementation that allows creating the database during an initialization step. Each film grain pattern is synthesized using a different pair of cut frequencies according to the frequency filtering model. The cut frequencies transmitted in the SEI message are used to access the database of film grain patterns during the film grain simulation process.

1.5.2 Uniform pseudo-random number generator

A uniform pseudo-random number generator, using a primitive polynomial modulo 2 operator, $x^{31} + x^3 + 1$, is used to randomly select film grain blocks of 8×8 samples from the film grain patterns of 64×64 samples stored in the database. The primitive polynomial modulo 2 operator shall be implemented in a 32-bit shift register. At each stage, two random numbers will be extracted from the register by taking the 16 most-significant bits (MSB) and 16 least-significant bits (LSB), as indicated in Figure 1-1.

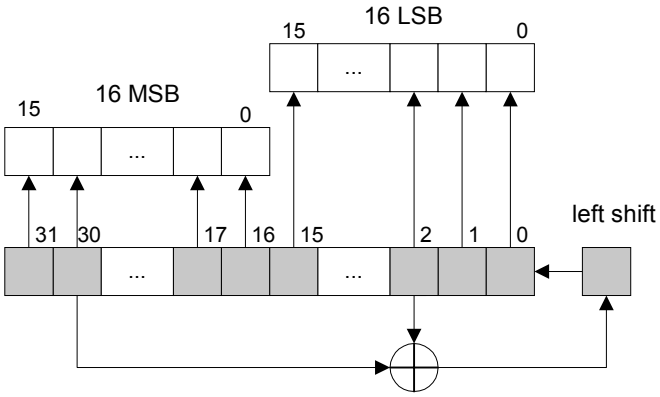

Figure 1-1 – Shift register with a primitive polynomial modulo 2

The pseudo-random number generator shall be updated before getting a new value from the 32-bit shift register.

1.5.2.1 Seed initialization

The seed of the pseudo-random number generator used to simulate film grain on the color component c shall be initialized at the beginning of each frame according to the following equation:

$$e_c = \text{Seed\_LUT}[\ \text{Mod}(\text{pic\_offset} + \text{color\_offset}[\ c\ ]), 256)\ ] \quad (1.1)$$

where

– pic_offset is defined in subclause 1.5.2.1.1 for H.264 | MPEG-4 AVC bitstreams;

- color_offset[0] = 0, color_offset[1] = 85 and color_offset[2] = 170 provide a different offset for each color component; and finally
- Seed_LUT is defined in subclause 2.2.2.

1.5.2.1.1 'pic_offset' definition

When decoding H.264 | MPEG-4 AVC bitstreams, pic_offset is defined as follows:

pic_offset = PicOrderCnt(CurrPic) + (PicOrderCnt_offset << 5) (1.1a)

where:

- PicOrderCnt(CurrPic) is the picture order count of the current frame, which shall be derived from the video stream as specified in the ITU-T Rec. H.264 | ISO/IEC 14496-10 standard.
- PicOrderCnt_offset is set to idr_pic_id on IDR frames. idr_pic_id shall be read from the slice header of a ITU-T Rec. H.264 | ISO/IEC 14496-10 video stream. On non-IDR I frames, PicOrderCnt_offset is set to 0. A frame shall be classified as I frame when all its slices are I slices, which may be optionally designated by setting primary_pic_type to 0 in the access delimiter NAL unit. Otherwise, PicOrderCnt_offset it not changed. PicOrderCnt_offset is updated in decoding order.

To ensure proper film grain simulation, successive IDR frames shall not have the same idr_pic_id. Additionally, any two IDR frames 32 or fewer frames apart (in decoding order) shall not have the same idr_pic_id.

1.5.3 Sequence of operations

The sequence of operations performed to simulate and add film grain to the decoded frame samples is shown in Figure 1-2. The description that follows can be particularized to any color component by setting c equal to 0, 1 or 2.

Film grain simulation shall be performed on the decoded frame, before applying any cropping rectangle specified explicitly or implicitly in the bitstream.

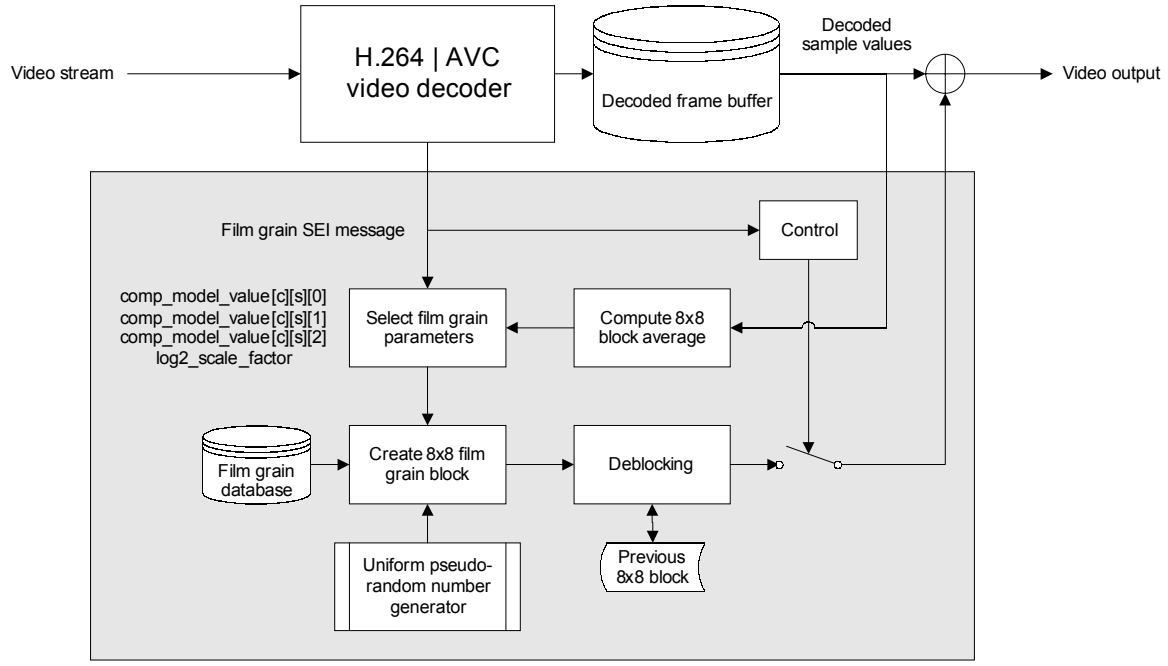

Figure 1-2 – Film grain simulation process

The current specifications require film grain simulation to be performed in raster scan order. It is assumed a raster scan order of blocks of 8×8 samples, but other implementations are possible.

1.5.3.1 Scale chroma film grain model values

Upon receipt of a film grain characteristics SEI message, cut frequencies of the chroma components (c = 1, 2) shall be scaled in order to adapt to the 4:2:0 chroma format:

```
for( c = 1; c < 3; c++)
  if( comp_model_present_flag[ c ] )
    for( i = 0; i <= num_intensity_intervals_minus1[ c ]; i++) {
      comp_model_value[ c ][ i ][ 0 ] >>= 1                                    (1.2)
      comp_model_value[ c ][ i ][ 1 ] = Clip(2, 14, (comp_model_value[ c ][ i ][ 1 ] << 1))
      comp_model_value[ c ][ i ][ 2 ] = Clip(2, 14, (comp_model_value[ c ][ i ][ 2 ] << 1))
    }
```

1.5.3.2 Select film grain parameters

For each non-overlapping 8×8 sample block from color component c of the decoded frame, the sample average value shall be computed as follows:

```
avg = 0
for( k = 0; k < 8; k++ )
  for( l = 0; l < 8; l++ )
    avg += decoded_frame[ c ][ m + k ][ n + l ]                                (1.3)
avg = avg >> 6
```

where (m,n) are the coordinates of the top-left corner of the block and decoded_frame[c][m + k][n + l] is the decoded sample value at coordinates (m + k, n + l) of color component c.

The average value is compared to the SEI message **intensity_interval_lower_bound[c][i]** and **intensity_interval_upper_bound[c][i]** parameters, i ranging from 0 to num_intensity_intervals_minus1[c]. The value of i for which the block average value is larger or equal than **intensity_interval_lower_bound[c][i]** and smaller or equal than **intensity_interval_upper_bound[c][i]**, denoted by s, shall be used to select the film grain parameters for the current block. If there is no value fulfilling the previous condition, no film grain simulation is performed on the current block. In such case, the film grain block creation process (subclause 1.5.3.3) shall be skipped and the input to the deblocking filter (subclause 1.5.3.4) shall be an 8×8 block with all its samples equal to zero.

1.5.3.3 Creation of a film grain block of 8×8 samples

The creation of a film grain block of 8×8 samples involves two steps: retrieving a block of 8×8 film grain samples from the database, and scaling those samples to the proper intensity. The cut frequencies comp_model_value[c][s][1] and comp_model_value[c][s][2] determine which pattern of the database is used as source of film grain samples and two randomly generated values select an 8×8 block from it. These random values represent a horizontal and vertical offset within the 64×64 sample pattern and are created using the following procedure:

```
k_offset = (MSB16(x(r, ec)) % 52)
k_offset &= 0xFFFC                                                             (1.4)
k_offset += m & 0x0008
```

```
l_offset = (LSB16(x(r, ec)) % 56)
l_offset &= 0xFFF8                                                             (1.5)
l_offset += n & 0x0008
```

where $x(r, e_c)$ indicates the r-th symbol of the sequence x of pseudo-random numbers initiated with the seed e_c, MSB_{16} and LSB_{16} denote the 16 most significant bits and 16 least significant bits, respectively, and (m,n) is the offset of the top-left corner of the current 8×8 block in the decoded frame. For the k_offset, the first equation generates a pseudo-random value uniformly distributed in the range [0,51], the second equation restricts that value to multiples of 4, and the last equation adds 8 to k_offset when m%16 equals 8. Equivalent operations are performed for the l_offset.

The pseudo-random value $x(r, e_c)$, created using the pseudo-random number generator presented in subclause 1.5.2, shall be updated in raster-scan order every 16 columns (horizontally) and every 16 lines (vertically), starting at the top-left corner and ending at the bottom-right corner of the decoded component c. The same pseudo-random number $x(r, e_c)$ shall be used in each non-overlapping area of 16×16 samples of the decoded component c. As illustrated in Figure 1-3, the resulting sequence of pseudo-random values $x(r, e_c)$ follows raster scan order over a 16×16 sample grid.

After computing the random offsets, 64 film grain values are extracted from the database and scaled as follows:

scale_factor = (BIT_0(x(r, e_c)) == 0) ? comp_model_value[c][s][0] : -comp_model_value[c][s][0]

```
for( k = 0; k < 8; k++)
  for( l = 0; l < 8; l++) {                                                    (1.6)
     g = scale_factor * database[ h ][ v ][ k + k_offset ][ l + l_offset ]
     fg_block[ k ][ l ] = g >> (log2_scale_factor + 6)
  }
```

where h is equal to comp_model_value[c][s][1] - 2, v is equal to comp_model_value[c][s][2] - 2, the factor 6 scales the film grain values derived from the process described in subclause 2.1, and BIT_0 denotes the LSB.

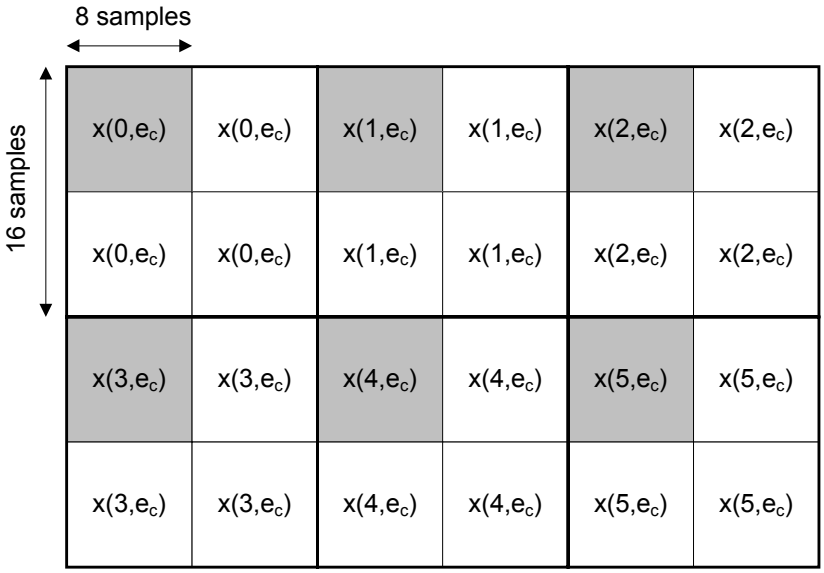

Figure 1-3 – Use of pseudo-random numbers in a decoded frame component

(For simplicity, this example assumes a 48×32 sample component.)

1.5.3.4 Deblocking vertical edges between adjacent blocks

As suggested in [1], a deblocking filter shall be applied between adjacent film grain blocks to ensure the seamless formation of film grain patterns. According to the present specifications, the deblocking filter applies only to the vertical edges between adjacent blocks. Assuming film grain blocks are simulated in raster scan order and that the left-most samples of fg_block are adjacent to the right-most samples of previous_fg_block, the deblocking filter shall be performed by means of a 3-tap filter as follows:

```
for( k = 0; k < 8; k++){
   l1 = previous_fg_block[ 6 ][ k ]
   l0 = previous_fg_block[ 7 ][ k ]
   r0 = fg_block[ 0 ][ k ]                                                    (1.7)
   r1 = fg_block[ 1 ][ k ]
   fg_block[ 0 ][ k ] = (l0 + (r0 << 1) + r1) >> 2
   previous_fg_block[ 7 ][ k ] = (l1 + (l0 << 1) + r0) >> 2
}
```

1.5.3.5 Blending the film grain with the decoded frame

At the end of the film grain simulation process, a deblocked film grain block is added to the corresponding decoded frame block and the result is clipped to [0, 255] prior to display:

```
for( k = 0; k < 8; k++)
  for( l = 0; l < 8; l++)                                                     (1.8)
        output_frame[ c ][ m + k ][ n + l ] = Clip(0, 255, decoded_frame[ c ][ m + k ][ n + l ] +
                                                    fg_block[ k ][ l ])
```

where (m,n) are the coordinates of the top-left corner of the block, decoded_frame[c][m + k][n + l] is the decoded sample value at coordinates (m + k, n + l) of color component c and display_frame[c][m + k][n + l] is the video output at the same coordinates. Note that decoded_frame represents a complete color frame while fg_block represents a single 8×8 sample block of film grain samples for color component c.

2 Film Grain Database Definition

This subclause forms an integral part of the specifications for bit-accurate film grain simulation. According to these specifications, a bit-accurate representation of the film grain pattern database can be accomplished either by storing a pre-computed list of values or by computing the values through an initialization process. Both approaches are compliant with the present specifications.

2.1 Database creation process

Bit-accurate creation of the database is accomplished by specifying: a LUT of Gaussian random numbers; a uniform pseudo-random number generator; an integer transform; and a precise sequence of operations. The following subclauses describe the creation process of a 64×64 film grain pattern with horizontal cut frequency h+2 and vertical cut frequency v+2, denoted by database[h][v]. The database creation process requires the creation of all the possible patterns database[h][v], where h and v are in the range of 0 to 12.

2.1.1 Creation of a 64×64 block image

To form an individual 64×64 block image, up to 4,096 values are read from a LUT of Gaussian random numbers. The LUT of Gaussian random numbers, provided in subclause 2.2.1 of the current specifications, is composed of 2,048 values stored in 2's complement form and ranging from -127 to 127. The uniform Pseudo-Random Number Generator (PRNG) defined in subclause 1.5.2 is used to randomly access the LUT of Gaussian random numbers.

In an initialization step, the values of the 64×64 block image shall be set to zero and the seed of the PRNG shall be initialized as follows:

e_{hv} = Seed_LUT[h + v * 13] (2.1)

The 64×64 block image shall be created as follows:

f_h = ((h+3) << 2) - 1
f_v = ((v+3) << 2) - 1

```
for( l = 0, r = 0; l <= fv; l++ )
  for( k = 0; k <= fh; k += 4 ) {
        B[ k ][ l ] = Gaussian_LUT[ x(r, ehv) % 2,048 ]
        B[ k + 1 ][ l ] = Gaussian_LUT[ (x(r, ehv) + 1) % 2,048 ]
        B[ k + 2 ][ l ] = Gaussian_LUT[ (x(r, ehv) + 2) % 2,048 ]
        B[ k + 3 ][ l ] = Gaussian_LUT[ (x(r, ehv) + 3) % 2,048 ]
        r++
  }
B[ 0 ][ 0 ] = 0
```

(2.2)

where x(r, e_{hv}) is the pseudo-random value created at iteration r of the polynomial x initialized at seed e_{hv}.

2.1.2 Computation of a 64×64 inverse integer transform

The film grain pattern database[h][v] will be obtained by inverse transformation and clipping of the 64×64 matrix of coefficients. The inverse transform shall be computed as follows:

$$\mathbf{b} = (((\mathbf{R}_{64}{}^{T} \times \mathbf{B} + 128) >> 8) \times \mathbf{R}_{64} + 128) >> 8 \quad (2.3)$$

where $\mathbf{R}_{64}$ is defined in subclause 2.2.3.

The clipping of the inverse transformed coefficients shall be performed as follows, and the result shall be stored at the corresponding location of the film grain pattern database:

database[h][v] = Clip(-127, 127, **b**) (2.4)

2.1.3 Deblocking of horizontal 8×8 block edges

The final step in the creation process of a 64×64 film grain pattern consists in the deblocking of horizontal 8×8 block edges. Deblocking is performed by attenuation of sample values according to the following equation:

```
for( l = 0; l < 64; l += 8 )
  for( k = 0; k < 64; k++ ) {
    database[ h ][ v ][ k ][ l ] = (database[ h ][ v ][ k ][ l ] * deblock_factor [ v ] ) >> 7
    database[ h ][ v ][ k ][ l + 7 ] = (database[ h ][ v ][ k ][ l + 7 ] * deblock_factor[ v ] ) >> 7
  }
```

where deblock_factor[v] is defined as:

deblock_factor[v] = { 64, 71, 77, 84, 90, 96, 103, 109, 116, 122, 128, 128, 128 }

2.2 Pre-defined values

2.2.1 LUT of Gaussian random numbers

```
Gaussian_LUT[2048] =
{
   -11,   12,  103,  -11,   42,  -35,   12,   59,   77,   98,  -87,    3,   65,  -78,   45,   56,
   -51,   21,   13,  -11,  -20,  -19,   33, -127,   17,   -6, -105,   18,   19,   71,   48,  -10,
   -38,   42,   -2,   75,  -67,   52,  -90,   33,  -47,   21,   -3,  -56,   49,    1,  -57,  -42,
    -1,  120, -127, -108,  -49,    9,   14,  127,  122,  109,   52,  127,    2,    7,  114,   19,
    30,   12,   77,  112,   82,  -61, -127,  111,  -52,  -29,    2,  -49,  -24,   58,  -29,  -73,
    12,  112,   67,   79,   -3, -114,  -87,   -6,   -5,   40,   58,  -81,   49,  -27,  -31,  -34,
  -105,   50,   16,  -24,  -35,  -14,  -15, -127,  -55,  -22,  -55, -127, -112,    5,  -26,  -72,
   127,  127,   -2,   41,   87,  -65,  -16,   55,   19,   91,  -81,  -65,  -64,   35,   -7,  -54,
    99,   -7,   88,  125,  -26,   91,    0,   63,   60,  -14,  -23,  113,  -33,  116,   14,   26,
    51,  -16,  107,   -8,   53,   38,  -34,   17,   -7,    4,  -91,    6,   63,   63,  -15,   39,
   -36,   19,   55,   17,  -51,   40,   33,  -37,  126,  -39, -118,   17,  -30,    0,   19,   98,
    60,  101,  -12,  -73,  -17,  -52,   98,    3,    3,   60,   33,   -3,   -2,   10,  -42, -106,
   -38,   14,  127,   16, -127,  -31,  -86,  -39,  -56,   46,  -41,   75,   23,  -19,  -22,  -70,
    74,  -54,   -2,   32,  -45,   17,  -92,   59,  -64,  -67,   56, -102,  -29,  -87,  -34,  -92,
    68,    5,  -74,  -61,   93,  -43,   14,  -26,  -38, -126,  -17,   16, -127,   64,   34,   31,
    93,   17,  -51,  -59,   71,   77,   81,  127,  127,   61,   33, -106,  -93,    0,    0,   75,
   -69,   71,  127,  -19, -111,   30,   23,   15,    2,   39,   92,    5,   42,    2,   -6,   38,
    15,  114,  -30,  -37,   50,   44,  106,   27,  119,    7,  -80,   25,  -68,  -21,   92,  -11,
    -1,   18,   41,  -50,   79, -127,  -43,  127,   18,   11,  -21,   32,  -52,   27,  -88,  -90,
   -39,  -19,  -10,   24, -118,   72,  -24,  -44,    2,   12,   86, -107,   39,  -33, -127,   47,
    51,  -24,  -22,   46,    0,   15,  -35,  -69,   -2,  -74,   24,   -6,    0,   29,   -3,   45,
    32,  -32,  117,  -45,   79,  -24,  -17, -109,  -10,  -70,   88,  -48,   24,  -91,  120,  -37,
    50, -127,   58,   32,  -82,  -10,  -17,   -7,   46, -127,  -15,   89,  127,   17,   98,  -39,
   -33,   37,   42,  -40,  -32,  -21,  105,  -19,   19,   19,  -59,   -9,   30,    0, -127,   34,
   127,  -84,   75,   24,  -40,  -49, -127, -107,  -14,   45,  -75,    1,   30,  -20,   41,  -68,
   -40,   12,  127,   -3,    5,   20,  -73,  -59, -127,   -3,   -3,  -53,   -6, -119,   93,  120,
   -80,  -50,    0,   20,  -46,   67,   78,  -12,  -22, -127,   36,  -41,   56,  119,   -5, -116,
   -22,   68,  -14,  -90,   24,  -82,  -44, -127,  107,  -25,  -37,   40,   -7,   -7,  -82,    5,
   -87,   44,  -34,    9, -127,   39,   70,   49,  -63,   74,  -49,  109,  -27,  -89,  -47,  -39,
    44,   49,   -4,   60,  -42,   80,    9, -127,   -9,  -56,  -49,  125,  -66,   47,   36,  117,
    15,  -11,  -96,  109,   94,  -17,  -56,   70,    8,  -14,   -5,   50,   37,  -45,  120,  -30,
   -76,   40,  -46,    6,    3,   69,   17,  -78,    1,  -79,    6,  127,   43,   26,  127, -127,
    28,  -55,  -26,   55,  112,   48,  107,   -1,  -77,   -1,   53,   -9,  -22,  -43,  123,  108,
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2.2.2 LUT of PRNG seeds

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2.2.3 Transformation matrix

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  -45,  -43,  -40,  -35,  -29,  -21,  -13,   -4,    4,   13,   21,   29,   35,   40,   43,   45},
```

```
{ /* Row 5 */
   45,   42,   37,   30,   20,   10,   -1,  -12,  -22,  -31,  -38,  -43,  -45,  -45,  -41,  -36,
  -28,  -18,   -8,    3,   14,   24,   33,   39,   44,   45,   44,   40,   34,   26,   16,    6,
   -6,  -16,  -26,  -34,  -40,  -44,  -45,  -44,  -39,  -33,  -24,  -14,   -3,    8,   18,   28,
   36,   41,   45,   45,   43,   38,   31,   22,   12,    1,  -10,  -20,  -30,  -37,  -42,  -45,
{ /* Row 6 */
   45,   41,   34,   23,   11,   -2,  -15,  -27,  -36,  -43,  -45,  -44,  -39,  -30,  -19,   -7,
    7,   19,   30,   39,   44,   45,   43,   36,   27,   15,    2,  -11,  -23,  -34,  -41,  -45,
  -45,  -41,  -34,  -23,  -11,    2,   15,   27,   36,   43,   45,   44,   39,   30,   19,    7,
   -7,  -19,  -30,  -39,  -44,  -45,  -43,  -36,  -27,  -15,   -2,   11,   23,   34,   41,   45},
{ /* Row 7 */
   45,   39,   30,   16,    1,  -14,  -28,  -38,  -44,  -45,  -40,  -31,  -18,   -3,   12,   26,
   37,   44,   45,   41,   33,   20,    6,  -10,  -24,  -36,  -43,  -45,  -42,  -34,  -22,   -8,
    8,   22,   34,   42,   45,   43,   36,   24,   10,   -6,  -20,  -33,  -41,  -45,  -44,  -37,
  -26,  -12,    3,   18,   31,   40,   45,   44,   38,   28,   14,   -1,  -16,  -30,  -39,  -45},
{ /* Row 8 */
   44,   38,   25,    9,   -9,  -25,  -38,  -44,  -44,  -38,  -25,   -9,    9,   25,   38,   44,
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   44,   38,   25,    9,   -9,  -25,  -38,  -44,  -44,  -38,  -25,   -9,    9,   25,   38,   44,
   44,   38,   25,    9,   -9,  -25,  -38,  -44,  -44,  -38,  -25,   -9,    9,   25,   38,   44},
{ /* Row 9 */
   44,   36,   20,    1,  -18,  -34,  -44,  -45,  -37,  -22,   -3,   16,   33,   43,   45,   38,
   24,    6,  -14,  -31,  -42,  -45,  -39,  -26,   -8,   12,   30,   41,   45,   40,   28,   10,
  -10,  -28,  -40,  -45,  -41,  -30,  -12,    8,   26,   39,   45,   42,   31,   14,   -6,  -24,
  -38,  -45,  -43,  -33,  -16,    3,   22,   37,   45,   44,   34,   18,   -1,  -20,  -36,  -44},
{ /* Row 10 */
   44,   34,   15,   -7,  -27,  -41,  -45,  -39,  -23,   -2,   19,   36,   45,   43,   30,   11,
  -11,  -30,  -43,  -45,  -36,  -19,    2,   23,   39,   45,   41,   27,    7,  -15,  -34,  -44,
  -44,  -34,  -15,    7,   27,   41,   45,   39,   23,    2,  -19,  -36,  -45,  -43,  -30,  -11,
   11,   30,   43,   45,   36,   19,   -2,  -23,  -39,  -45,  -41,  -27,   -7,   15,   34,   44},
{ /* Row 11 */
   44,   31,   10,  -14,  -34,  -45,  -42,  -28,   -6,   18,   37,   45,   40,   24,    1,  -22,
  -39,  -45,  -38,  -20,    3,   26,   41,   45,   36,   16,   -8,  -30,  -43,  -44,  -33,  -12,
   12,   33,   44,   43,   30,    8,  -16,  -36,  -45,  -41,  -26,   -3,   20,   38,   45,   39,
   22,   -1,  -24,  -40,  -45,  -37,  -18,    6,   28,   42,   45,   34,   14,  -10,  -31,  -44},
{ /* Row 12 */
   43,   29,    4,  -21,  -40,  -45,  -35,  -13,   13,   35,   45,   40,   21,   -4,  -29,  -43,
  -43,  -29,   -4,   21,   40,   45,   35,   13,  -13,  -35,  -45,  -40,  -21,    4,   29,   43,
   43,   29,    4,  -21,  -40,  -45,  -35,  -13,   13,   35,   45,   40,   21,   -4,  -29,  -43,
  -43,  -29,   -4,   21,   40,   45,   35,   13,  -13,  -35,  -45,  -40,  -21,    4,   29,   43},
{ /* Row 13 */
   43,   26,   -1,  -28,  -44,  -42,  -24,    3,   30,   44,   41,   22,   -6,  -31,  -45,  -40,
  -20,    8,   33,   45,   39,   18,  -10,  -34,  -45,  -38,  -16,   12,   36,   45,   37,   14,
  -14,  -37,  -45,  -36,  -12,   16,   38,   45,   34,   10,  -18,  -39,  -45,  -33,   -8,   20,
   40,   45,   31,    6,  -22,  -41,  -44,  -30,   -3,   24,   42,   44,   28,    1,  -26,  -43},
{ /* Row 14 */
   43,   23,   -7,  -34,  -45,  -36,  -11,   19,   41,   44,   27,   -2,  -30,  -45,  -39,  -15,
   15,   39,   45,   30,    2,  -27,  -44,  -41,  -19,   11,   36,   45,   34,    7,  -23,  -43,
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{ /* Row 15 */
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   41,   43,   22,  -10,  -37,  -45,  -30,    1,   31,   45,   36,    8,  -24,  -44,  -40,  -16,
   16,   40,   44,   24,   -8,  -36,  -45,  -31,   -1,   30,   45,   37,   10,  -22,  -43,  -41,
  -18,   14,   39,   44,   26,   -6,  -34,  -45,  -33,   -3,   28,   45,   38,   12,  -20,  -42},
{ /* Row 16 */
   42,   17,  -17,  -42,  -42,  -17,   17,   42,   42,   17,  -17,  -42,  -42,  -17,   17,   42,
   42,   17,  -17,  -42,  -42,  -17,   17,   42,   42,   17,  -17,  -42,  -42,  -17,   17,   42,
   42,   17,  -17,  -42,  -42,  -17,   17,   42,   42,   17,  -17,  -42,  -42,  -17,   17,   42,
   42,   17,  -17,  -42,  -42,  -17,   17,   42,   42,   17,  -17,  -42,  -42,  -17,   17,   42},
{ /* Row 17 */
   41,   14,  -22,  -44,  -37,   -6,   30,   45,   31,   -3,  -36,  -45,  -24,   12,   40,   42,
   16,  -20,  -44,  -38,   -8,   28,   45,   33,   -1,  -34,  -45,  -26,   10,   39,   43,   18,
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  -42,  -40,  -12,   24,   45,   36,    3,  -31,  -45,  -30,    6,   37,   44,   22,  -14,  -41},
{ /* Row 18 */
   41,   11,  -27,  -45,  -30,    7,   39,   43,   15,  -23,  -45,  -34,    2,   36,   44,   19,
  -19,  -44,  -36,   -2,   34,   45,   23,  -15,  -43,  -39,   -7,   30,   45,   27,  -11,  -41,
  -41,  -11,   27,   45,   30,   -7,  -39,  -43,  -15,   23,   45,   34,   -2,  -36,  -44,  -19,
   19,   44,   36,    2,  -34,  -45,  -23,   15,   43,   39,    7,  -30,  -45,  -27,   11,   41},
```

```
{ /* Row 19 */
   40,    8,  -31,  -45,  -22,   18,   44,   34,   -3,  -38,  -42,  -12,   28,   45,   26,  -14,
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   20,   45,   33,   -6,  -39,  -41,  -10,   30,   45,   24,  -16,  -44,  -36,    1,   37,   43,
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{ /* Row 20 */
   40,    4,  -35,  -43,  -13,   29,   45,   21,  -21,  -45,  -29,   13,   43,   35,   -4,  -40,
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   40,    4,  -35,  -43,  -13,   29,   45,   21,  -21,  -45,  -29,   13,   43,   35,   -4,  -40,
  -40,   -4,   35,   43,   13,  -29,  -45,  -21,   21,   45,   29,  -13,  -43,  -35,    4,   40},
{ /* Row 21 */
   39,    1,  -38,  -40,   -3,   37,   41,    6,  -36,  -42,   -8,   34,   43,   10,  -33,  -44,
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  -22,  -45,  -24,   20,   45,   26,  -18,  -45,  -28,   16,   45,   30,  -14,  -44,  -31,   12,
   44,   33,  -10,  -43,  -34,    8,   42,   36,   -6,  -41,  -37,    3,   40,   38,   -1,  -39},
{ /* Row 22 */
   39,   -2,  -41,  -36,    7,   43,   34,  -11,  -44,  -30,   15,   45,   27,  -19,  -45,  -23,
   23,   45,   19,  -27,  -45,  -15,   30,   44,   11,  -34,  -43,   -7,   36,   41,    2,  -39,
  -39,    2,   41,   36,   -7,  -43,  -34,   11,   44,   30,  -15,  -45,  -27,   19,   45,   23,
  -23,  -45,  -19,   27,   45,   15,  -30,  -44,  -11,   34,   43,    7,  -36,  -41,   -2,   39},
{ /* Row 23 */
   38,   -6,  -43,  -31,   16,   45,   22,  -26,  -45,  -12,   34,   41,    1,  -40,  -36,   10,
   44,   28,  -20,  -45,  -18,   30,   44,    8,  -37,  -39,    3,   42,   33,  -14,  -45,  -24,
   24,   45,   14,  -33,  -42,   -3,   39,   37,   -8,  -44,  -30,   18,   45,   20,  -28,  -44,
  -10,   36,   40,   -1,  -41,  -34,   12,   45,   26,  -22,  -45,  -16,   31,   43,    6,  -38},
{ /* Row 24 */
   38,   -9,  -44,  -25,   25,   44,    9,  -38,  -38,    9,   44,   25,  -25,  -44,   -9,   38,
   38,   -9,  -44,  -25,   25,   44,    9,  -38,  -38,    9,   44,   25,  -25,  -44,   -9,   38,
   38,   -9,  -44,  -25,   25,   44,    9,  -38,  -38,    9,   44,   25,  -25,  -44,   -9,   38,
   38,   -9,  -44,  -25,   25,   44,    9,  -38,  -38,    9,   44,   25,  -25,  -44,   -9,   38},
{ /* Row 25 */
   37,  -12,  -45,  -18,   33,   40,   -6,  -44,  -24,   28,   43,    1,  -42,  -30,   22,   45,
    8,  -39,  -34,   16,   45,   14,  -36,  -38,   10,   45,   20,  -31,  -41,    3,   44,   26,
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  -45,  -22,   30,   42,   -1,  -43,  -28,   24,   44,    6,  -40,  -33,   18,   45,   12,  -37},
{ /* Row 26 */
   36,  -15,  -45,  -11,   39,   34,  -19,  -45,   -7,   41,   30,  -23,  -44,   -2,   43,   27,
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   27,   43,   -2,  -44,  -23,   30,   41,   -7,  -45,  -19,   34,   39,  -11,  -45,  -15,   36},
{ /* Row 27 */
   36,  -18,  -45,   -3,   43,   24,  -31,  -39,   12,   45,   10,  -40,  -30,   26,   42,   -6,
  -45,  -16,   37,   34,  -20,  -44,   -1,   44,   22,  -33,  -38,   14,   45,    8,  -41,  -28,
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    6,  -42,  -26,   30,   40,  -10,  -45,  -12,   39,   31,  -24,  -43,    3,   45,   18,  -36},
{ /* Row 28 */
   35,  -21,  -43,    4,   45,   13,  -40,  -29,   29,   40,  -13,  -45,   -4,   43,   21,  -35,
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{ /* Row 29 */
   34,  -24,  -41,   12,   45,    1,  -45,  -14,   40,   26,  -33,  -36,   22,   42,  -10,  -45,
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   45,   10,  -42,  -22,   36,   33,  -26,  -40,   14,   45,   -1,  -45,  -12,   41,   24,  -34},
{ /* Row 30 */
   34,  -27,  -39,   19,   43,  -11,  -45,    2,   45,    7,  -44,  -15,   41,   23,  -36,  -30,
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{ /* Row 31 */
   33,  -30,  -36,   26,   38,  -22,  -40,   18,   42,  -14,  -44,   10,   45,   -6,  -45,    1,
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{ /* Row 32 */
   32,  -32,  -32,   32,   32,  -32,  -32,   32,   32,  -32,  -32,   32,   32,  -32,  -32,   32,
   32,  -32,  -32,   32,   32,  -32,  -32,   32,   32,  -32,  -32,   32,   32,  -32,  -32,   32,
   32,  -32,  -32,   32,   32,  -32,  -32,   32,   32,  -32,  -32,   32,   32,  -32,  -32,   32,
   32,  -32,  -32,   32,   32,  -32,  -32,   32,   32,  -32,  -32,   32,   32,  -32,  -32,   32},
```

```
{ /* Row 33 */
   31,  -34,  -28,   37,   24,  -39,  -20,   41,   16,  -43,  -12,   44,    8,  -45,   -3,   45,
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{ /* Row 34 */
   30,  -36,  -23,   41,   15,  -44,   -7,   45,   -2,  -45,   11,   43,  -19,  -39,   27,   34,
  -34,  -27,   39,   19,  -43,  -11,   45,    2,  -45,    7,   44,  -15,  -41,   23,   36,  -30,
  -30,   36,   23,  -41,  -15,   44,    7,  -45,    2,   45,  -11,  -43,   19,   39,  -27,  -34,
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{ /* Row 35 */
   30,  -38,  -18,   44,    6,  -45,    8,   43,  -20,  -37,   31,   28,  -39,  -16,   44,    3,
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   -3,  -44,   16,   39,  -28,  -31,   37,   20,  -43,   -8,   45,   -6,  -44,   18,   38,  -30},
{ /* Row 36 */
   29,  -40,  -13,   45,   -4,  -43,   21,   35,  -35,  -21,   43,    4,  -45,   13,   40,  -29,
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   29,  -40,  -13,   45,   -4,  -43,   21,   35,  -35,  -21,   43,    4,  -45,   13,   40,  -29,
  -29,   40,   13,  -45,    4,   43,  -21,  -35,   35,   21,  -43,   -4,   45,  -13,  -40,   29},
{ /* Row 37 */
   28,  -41,   -8,   45,  -14,  -38,   33,   22,  -44,   -1,   44,  -20,  -34,   37,   16,  -45,
    6,   42,  -26,  -30,   40,   10,  -45,   12,   39,  -31,  -24,   43,    3,  -45,   18,   36,
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   45,  -16,  -37,   34,   20,  -44,    1,   44,  -22,  -33,   38,   14,  -45,    8,   41,  -28},
{ /* Row 38 */
   27,  -43,   -2,   44,  -23,  -30,   41,    7,  -45,   19,   34,  -39,  -11,   45,  -15,  -36,
   36,   15,  -45,   11,   39,  -34,  -19,   45,   -7,  -41,   30,   23,  -44,    2,   43,  -27,
  -27,   43,    2,  -44,   23,   30,  -41,   -7,   45,  -19,  -34,   39,   11,  -45,   15,   36,
  -36,  -15,   45,  -11,  -39,   34,   19,  -45,    7,   41,  -30,  -23,   44,   -2,  -43,   27},
{ /* Row 39 */
   26,  -44,    3,   41,  -31,  -20,   45,  -10,  -38,   36,   14,  -45,   16,   34,  -39,   -8,
   45,  -22,  -30,   42,    1,  -43,   28,   24,  -44,    6,   40,  -33,  -18,   45,  -12,  -37,
   37,   12,  -45,   18,   33,  -40,   -6,   44,  -24,  -28,   43,   -1,  -42,   30,   22,  -45,
    8,   39,  -34,  -16,   45,  -14,  -36,   38,   10,  -45,   20,   31,  -41,   -3,   44,  -26},
{ /* Row 40 */
   25,  -44,    9,   38,  -38,   -9,   44,  -25,  -25,   44,   -9,  -38,   38,    9,  -44,   25,
   25,  -44,    9,   38,  -38,   -9,   44,  -25,  -25,   44,   -9,  -38,   38,    9,  -44,   25,
   25,  -44,    9,   38,  -38,   -9,   44,  -25,  -25,   44,   -9,  -38,   38,    9,  -44,   25,
   25,  -44,    9,   38,  -38,   -9,   44,  -25,  -25,   44,   -9,  -38,   38,    9,  -44,   25},
{ /* Row 41 */
   24,  -45,   14,   33,  -42,    3,   39,  -37,   -8,   44,  -30,  -18,   45,  -20,  -28,   44,
  -10,  -36,   40,    1,  -41,   34,   12,  -45,   26,   22,  -45,   16,   31,  -43,    6,   38,
  -38,   -6,   43,  -31,  -16,   45,  -22,  -26,   45,  -12,  -34,   41,   -1,  -40,   36,   10,
  -44,   28,   20,  -45,   18,   30,  -44,    8,   37,  -39,   -3,   42,  -33,  -14,   45,  -24},
{ /* Row 42 */
   23,  -45,   19,   27,  -45,   15,   30,  -44,   11,   34,  -43,    7,   36,  -41,    2,   39,
  -39,   -2,   41,  -36,   -7,   43,  -34,  -11,   44,  -30,  -15,   45,  -27,  -19,   45,  -23,
  -23,   45,  -19,  -27,   45,  -15,  -30,   44,  -11,  -34,   43,   -7,  -36,   41,   -2,  -39,
   39,    2,  -41,   36,    7,  -43,   34,   11,  -44,   30,   15,  -45,   27,   19,  -45,   23},
{ /* Row 43 */
   22,  -45,   24,   20,  -45,   26,   18,  -45,   28,   16,  -45,   30,   14,  -44,   31,   12,
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   39,   -1,  -38,   40,   -3,  -37,   41,   -6,  -36,   42,   -8,  -34,   43,  -10,  -33,   44,
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{ /* Row 44 */
   21,  -45,   29,   13,  -43,   35,    4,  -40,   40,   -4,  -35,   43,  -13,  -29,   45,  -21,
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  -21,   45,  -29,  -13,   43,  -35,   -4,   40,  -40,    4,   35,  -43,   13,   29,  -45,   21},
{ /* Row 45 */
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   43,  -37,    1,   36,  -44,   16,   24,  -45,   30,   10,  -41,   39,   -6,  -33,   45,  -20},
{ /* Row 46 */
   19,  -44,   36,   -2,  -34,   45,  -23,  -15,   43,  -39,    7,   30,  -45,   27,   11,  -41,
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  -41,   11,   27,  -45,   30,    7,  -39,   43,  -15,  -23,   45,  -34,   -2,   36,  -44,   19},
```

```
{ /* Row 47 */
   18,  -43,   39,  -10,  -26,   45,  -34,    1,   33,  -45,   28,    8,  -38,   44,  -20,  -16,
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   41,  -14,  -22,   44,  -37,    6,   30,  -45,   31,    3,  -36,   45,  -24,  -12,   40,  -42,
   16,   20,  -44,   38,   -8,  -28,   45,  -33,   -1,   34,  -45,   26,   10,  -39,   43,  -18},
{ /* Row 48 */
   17,  -42,   42,  -17,  -17,   42,  -42,   17,   17,  -42,   42,  -17,  -17,   42,  -42,   17,
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   17,  -42,   42,  -17,  -17,   42,  -42,   17,   17,  -42,   42,  -17,  -17,   42,  -42,   17,
   17,  -42,   42,  -17,  -17,   42,  -42,   17,   17,  -42,   42,  -17,  -17,   42,  -42,   17},
{ /* Row 49 */
   16,  -40,   44,  -24,   -8,   36,  -45,   31,   -1,  -30,   45,  -37,   10,   22,  -43,   41,
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  -42,   20,   12,  -38,   45,  -28,   -3,   33,  -45,   34,   -6,  -26,   44,  -39,   14,   18,
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{ /* Row 50 */
   15,  -39,   45,  -30,    2,   27,  -44,   41,  -19,  -11,   36,  -45,   34,   -7,  -23,   43,
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  -15,   39,  -45,   30,   -2,  -27,   44,  -41,   19,   11,  -36,   45,  -34,    7,   23,  -43,
   43,  -23,   -7,   34,  -45,   36,  -11,  -19,   41,  -44,   27,    2,  -30,   45,  -39,   15},
{ /* Row 51 */
   14,  -37,   45,  -36,   12,   16,  -38,   45,  -34,   10,   18,  -39,   45,  -33,    8,   20,
  -40,   45,  -31,    6,   22,  -41,   44,  -30,    3,   24,  -42,   44,  -28,    1,   26,  -43,
   43,  -26,   -1,   28,  -44,   42,  -24,   -3,   30,  -44,   41,  -22,   -6,   31,  -45,   40,
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{ /* Row 52 */
   13,  -35,   45,  -40,   21,    4,  -29,   43,  -43,   29,   -4,  -21,   40,  -45,   35,  -13,
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   13,  -35,   45,  -40,   21,    4,  -29,   43,  -43,   29,   -4,  -21,   40,  -45,   35,  -13,
  -13,   35,  -45,   40,  -21,   -4,   29,  -43,   43,  -29,    4,   21,  -40,   45,  -35,   13},
{ /* Row 53 */
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   39,  -45,   38,  -20,   -3,   26,  -41,   45,  -36,   16,    8,  -30,   43,  -44,   33,  -12},
{ /* Row 54 */
   11,  -30,   43,  -45,   36,  -19,   -2,   23,  -39,   45,  -41,   27,   -7,  -15,   34,  -44,
   44,  -34,   15,    7,  -27,   41,  -45,   39,  -23,    2,   19,  -36,   45,  -43,   30,  -11,
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{ /* Row 55 */
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   38,  -45,   43,  -33,   16,    3,  -22,   37,  -45,   44,  -34,   18,    1,  -20,   36,  -44,
   44,  -36,   20,   -1,  -18,   34,  -44,   45,  -37,   22,   -3,  -16,   33,  -43,   45,  -38,
   24,   -6,  -14,   31,  -42,   45,  -39,   26,   -8,  -12,   30,  -41,   45,  -40,   28,  -10},
{ /* Row 56 */
    9,  -25,   38,  -44,   44,  -38,   25,   -9,   -9,   25,  -38,   44,  -44,   38,  -25,    9,
    9,  -25,   38,  -44,   44,  -38,   25,   -9,   -9,   25,  -38,   44,  -44,   38,  -25,    9,
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    9,  -25,   38,  -44,   44,  -38,   25,   -9,   -9,   25,  -38,   44,  -44,   38,  -25,    9},
{ /* Row 57 */
    8,  -22,   34,  -42,   45,  -43,   36,  -24,   10,    6,  -20,   33,  -41,   45,  -44,   37,
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  -37,   44,  -45,   41,  -33,   20,   -6,  -10,   24,  -36,   43,  -45,   42,  -34,   22,   -8},
{ /* Row 58 */
    7,  -19,   30,  -39,   44,  -45,   43,  -36,   27,  -15,    2,   11,  -23,   34,  -41,   45,
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{ /* Row 59 */
    6,  -16,   26,  -34,   40,  -44,   45,  -44,   39,  -33,   24,  -14,    3,    8,  -18,   28,
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{ /* Row 60 */
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```

```
{ /* Row 61 */
    3,  -10,   16,  -22,   28,  -33,   37,  -40,   43,  -45,   45,  -45,   44,  -41,   38,  -34,
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   34,  -38,   41,  -44,   45,  -45,   45,  -43,   40,  -37,   33,  -28,   22,  -16,   10,   -3},
{ /* Row 62 */
    2,   -7,   11,  -15,   19,  -23,   27,  -30,   34,  -36,   39,  -41,   43,  -44,   45,  -45,
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{ /* Row 63 */
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};
```