

Readerboard  
User's Guide  
WORKING  
DRAFT

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## HARDWARE

People who are really serious  
about software should make  
their own hardware.

—Alan Kay

**A**S A HOBBY PROJECT, the design of the hardware and software for the reader-board project “grew in the telling” as new ideas sprang to mind. As of this writing, there are three different models of hardware prototypes which were designed and created.

### Version 1.0

The initial prototype (PCB 1.0.1) was a fairly large board, approximately  $20\frac{5}{8} \times 6\frac{5}{8}$ ” with an LED pitch of  $\frac{1}{8}$ ”.

It requires an Arduino Mega 2560 or Arduino Due to drive it. A custom-made shield board attaches to the Arduino, which provides connectors for power and ribbon cables to drive the display (one to control the matrix, the other for the 8 status LEDs which appear in a horizontal row along the bottom right of the matrix).

### Version 2.0

This version is based on the 1.0 design, but shrunk to a board size of about  $18\frac{3}{16} \times 5\frac{3}{16}$ ” with an LED pitch of  $\frac{1}{4}$ ”. It also replaces the obsolete TPIC6B595 with the newer STPIC6D595 chip. It also relocates the ribbon cable which

connects the Arduino controller to the LED matrix, moves the eight status LEDs to a vertical column to the right of the matrix, and switches to resistor arrays for the matrix current limiting resistors, instead of the individual discrete resistors used on the 1.0.1 board.

## Version 2.1

Version 2.1 is a significant change to the 2.0 board in terms of how it interfaces with the Arduino, although it has the same size and physical layout as the 2.0 board.

This one eliminates the need for the ribbon cables and shield board. Instead, the Arduino controller mounts directly to the back of the display board. This means that the lower portion of the left edge of the enclosure has all of the external connections in one place, including power, RS-485 in and out, and the USB connector(s) on the Arduino itself.

## Version 3.2

The current version of the hardware expands on the version 2.1 design by replacing the single-color LEDs with RGB LEDs arranged into 24 logical rows—each of the eight physical rows is logically a row of red, green, and blue LED elements.

As of this writing, the current revision of this board is schematic version 3.2.3 and PCB version 3.2.2.

## Firmware Implications

The boards for versions 1.0 and 2.0 were compatible and used the same Arduino shield. Thus, they use the same firmware images. The 2.1 board, however, which integrates the Arduino directly instead of using a separate shield with ribbon cables, assigns signals to different I/O pins, and as such needs a different firmware image.

Both images are generated from the same source files, with compile-time switches to make one or the other.

Version 3.2 expands the number of logical rows due to the RGB implementation, which requires corresponding changes to the firmware and protocol to support the new color data.

*At this point in development it is unclear whether we'll continue making the different versions available using compile-time switches or if we'll just support this version going forward.*

## Construction

Once you have created a printed circuit board (PCB) from the fabrication files included with the readerboard Git repository and obtained the parts



Part No.	Qty	Mouser	Description
	1		Printed circuit board rev 3.2.2
	1		Arduino Due or Mega 2560
C0–9,11,12	12	810-FA18X7R1H10400	0.1 $\mu$ F capacitor
C10	1	667-ECA-1HM100I	10 $\mu$ F electrolytic capacitor
D0–511	512		LED, 5mm, RGB, common cathode
D512	1		LED, 5mm, green
D513–14	2		LED, 5mm, yellow
D515–16	2		LED, 5mm, red
D517–18	2		LED, 5mm, blue
D519	1		LED, 5mm, white
J0	1		Arduino stacking pin set
J1	1		8-position Euro-style terminal block
J2	1		2-position jumper header
P0	1		2-position jumper shunt
Q0–23	24	942-IRF9530NPBF	IRF9530 p-channel MOSFET
R0–7,35–50	24	604-MFR-24FRF521K	1K resistor
R8–23	16		4 $\times$ 360 $\Omega$ resistor array, isolated
R24,29–31	4	603-MFR-25FTE52-300R	300 $\Omega$ resistor
R25–28	4		360 $\Omega$ resistor
R32–34	3	603-MFR-25FRF5210K	10K resistor
Rterm	1		120 $\Omega$ resistor
U0,12,13	3	595-CD74HCT238PWR	CD74HCT238PWR non-inverting 3-to-8 decoder
U1,2,14,15	4		ULN2803CDWR octal NPN Darlington array
U3–10	8		STPIC6D595MTR power 8-bit shift register
U11	1		THVD1439 half-duplex RS-485 driver/receiver
	24		TO-220 heat sinks for Q0–23
	1		9V 2A DC power supply

Figure 1.1: Bill of Materials

as listed in Figure 1.1, carefully solder the components in place.

**Warning! Danger! Only perform the assembly operation if you are qualified to do so. Soldering electronic components may be hazardous due to the high temperatures, sharp objects, electrical voltages, potentially toxic materials, and other dangers. This requires skill and expertise as well as personal protection equipment to perform safely.** Please also observe all precautions to avoid damaging the electronic components themselves from harm due to heat or static electricity discharge.

### Suggested Order

For best results, solder components in a way that allows best access to the solder points without some parts getting in the way of connecting subsequent ones. For example:

1. Solder all the surface mount chips first: U0–U15.
  - U0, U12, U13: CD74HCT238PWR
  - U1, U2, U14, U15: ULN2803CDWR (ULN2803A SOP-18 packages may be used if aligned to the top 18 pads, leaving the bottom two empty, if they have otherwise identical pinouts and characteristics)
  - U3–U10: STPIC6D595MTR
  - U11: THVD1439DR
2. Solder the discrete resistors: R0–R7, R24–R50. See below first to ensure the correct values are used for R24–R31.
  - R0–R7, R35–50: 1K
  - R24, R29–R31:  $300\Omega$
  - R25–R28:  $360\Omega$
  - R32–R34: 10K
3. Solder the  $0.1\mu\text{F}$  capacitors: C0–C9, C11–C12.
4. Solder the resistor arrays: R8–R23.
5. Solder the RGB LEDs D0–D511. Ensure that the common cathode goes to pin 2 so that pins 1, 3, and 4 are respectively the red, green, and blue anodes.
6. Solder the single-color LEDs D512–D519 in the colors of your choice, being mindful of the polarity. The anode has a square pin on the PCB. Our recommendation:
  - D512 (bottom): green (with  $R24=300\Omega$ )<sup>1</sup>
  - D513: yellow (with  $R25=360\Omega$ )
  - D514: yellow (with  $R26=360\Omega$ )
  - D515: red (with  $R27=360\Omega$ )
  - D516: red (with  $R28=360\Omega$ )
  - D517: blue (with  $R29=300\Omega$ )
  - D518: blue (with  $R30=300\Omega$ )

---

<sup>1</sup>Resistor values based on typical LED voltage and current ratings. Check to see what is appropriate for your components.

- D519 (top): white (with R31=300 $\Omega$ )
7. Solder the 10 $\mu$ F capacitor C10, being mindful of the correct polarity.
  8. Solder the Arduino bus stacking pins (six sets—1 $\times$ 10-pin, 5 $\times$ 8-pin—all labeled collectively at J0). Ensure the pins extend down and out the back of the board.
  9. Solder the 2-pin header J2.
  10. Solder the terminal block J1.

### **Option: Using Single-Color LEDs**

If you don't need RGB LEDs for your application, the same PCB may be used with single-color 5mm LEDs instead. Simply solder them onto the board so that their cathode is on pin 2 and the anode is on pin 4 of the LED footprint. This means the LEDs will electrically all be connected to the blue circuit.

Since they won't be used, omit parts U0, U2, U12, U14, C0, C11, Q0–Q15, R0–R7, and R35–R42.

Either tell the readerboard to light up all of its content in the blue color (since that's what will be driving your LEDs regardless of their actual color), or make a firmware change so that the readerboard disregards any color specification except black, lighting up the single-color LEDs for all other colors.



## CHAPTER 2

### PROTOCOL DESCRIPTION

I don't stand on protocol. Just call me  
your Excellency.

—Henry Kissinger

**T**HE CONTROL PROTOCOL used to display information on the readerboard sign is very simple. Commands are expressed largely in plain ASCII characters and are executed immediately as they are received.<sup>1</sup>

In addition to plain, printable 7-bit ASCII characters, a few control codes are recognized as described below. String data may include any 8-bit value except as otherwise indicated.

#### Web Service API

The organization of the rest of this chapter is oriented toward a description of the protocol used to control the hardware directly over a USB or RS-485 connection. However, you can set up a central server which is connected to all the readerboard signs and busylight indicators in a small area (via USB or RS-485). This allows clients to send commands to the server over the network for control of the readerboards.

The protocol between clients and servers uses messages which are simple HTTP requests posted to the server's listening port URL. If the server were configured to run on `example.org` on port 43210, then all client requests to that server would begin with

`http://example.org:43210/readerboard/v1/<message>?a=<targets>`

---

<sup>1</sup>Technically, they may even be executed *while* they are being received.

## Message Data Fields

As a general rule, if a message expects a field that is not provided, a suitable “zero” value will be assumed for that field. Any extra fields sent that were not expected are silently ignored.

Boolean fields may have values `true` or `false`; if they are presented without a value, they are considered to be `true`, and if completely missing they are assumed to be `false`. Thus,

`.../readerboard/v1/<message>?a=<targets>&status=true`

is equivalent to

`.../readerboard/v1/<message>?a=<targets>&status`

and

`.../readerboard/v1/<message>?a=<targets>&status=false`

is equivalent to

`.../readerboard/v1/<message>?a=<targets>`

## Message Target Addresses

Every message also has a field called “a” which is a comma-separated list of target readerboards to which the message applies.

So, for example, the message containing `a=2` would cause the server to transmit the corresponding command to the readerboard with address 2 directly connected to it via USB, or would transmit to the RS-485 network the command starting with the hex byte 92.

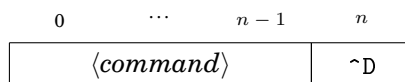
If multiple devices are targeted, say with a message containing the field `a=2,5,37` with address 15 (e.g.,  $F_{16}$ ) configured as the global address  $ad_G$ , it will transmit to the RS-485 network a command starting with the hex byte sequence BF 03 02 05 25.

## USB vs. RS-485

The protocol used to send commands to the readerboard is different depending on whether the host is sending directly to a single readerboard over a USB cable, or to (possibly) multiple readerboards over an RS-485 bus network.

### USB

A readerboard connected via USB accepts the commands just as documented below, with the addition that each such command is terminated by a `^D` byte (hex value  $04_{16}$ ).



If there is an error parsing or executing a command, the readerboard will ignore all subsequent input until a  $\text{^D}$  is received, whereupon it will expect to see the start of another command. Thus,  $\text{^D}$  may not appear in any transmitted data except to terminate commands.

Commands which contain arbitrary-size data fields, such as text strings or lists of LEDs to light in sequence, end such fields with a terminator byte. In most cases this may be either a dollar-sign (“\$”) character or the escape control character (hex byte  $1\text{B}_{16}$ ), indicated in the protocol diagram above simply as “\$”. In cases where a dollar-sign could be part of the data, then only an escape character may be used to terminate the field, in which case the protocol description will show the terminator as “ESC”.

## RS-485

Commands sent over RS-485 are intended to target one or more of a set of connected readerboards over a network which may also contain other Lumos-protocol-compatible devices, so they adhere to a protocol that is also compatible with those devices.

Each command begins with one of the following binary headers, depending on the set of target readerboard signs which should obey the command.

### Single Target or All Readerboards

To send a command to a single sign, begin with a single byte encoded as:

7	6	5	4	3	2	1	0
1	0	0	1	$\langle ad \rangle$			

where  $\langle ad \rangle$  is the sign’s address on the bus, which must be a value in the range 0–15. This byte is followed by any command as described below. If the global address  $ad_G$  is given as the  $\langle ad \rangle$  value, then all readerboards which have that set as their global address will obey the command.

### Multiple Targets

Alternatively, a command may be targeted to multiple signs by starting the command with a multi-byte code:

7	6	5	4	3	2	1	0				
1	0	1	1	$\langle ad_G \rangle$							
0	0	$\langle n \rangle$									
0	0							$\langle ad_0 \rangle$			
$\vdots$											
0	0	$\langle ad_{n-1} \rangle$									

where  $\langle ad_G \rangle$  is the “global” device address which signals readerboards generally (see the = command below). This will send to the  $\langle n \rangle$  devices addressed as  $\langle ad_0 \rangle$  through  $\langle ad_{n-1} \rangle$ .

Note that device addresses are constrained to the range 0–15 if they are to be addressed in the command start byte. However, using the multiple target header, device addresses in the range 0–63 may be used.

### All Off

As a special case, the single byte

7	6	5	4	3	2	1	0
1	0	0	0	$\langle ad \rangle$			

will cause the readerboard addressed as  $\langle ad \rangle$  to turn off all LEDs. If  $\langle ad \rangle$  is the  $ad_G$  address, then all readerboards will turn off all LEDs.

No other command bytes need to follow; this byte is sufficient to turn off the sign(s).

The corresponding HTTP message is `/readerboard/v1/alloff?a= $\langle ad \rangle$`

### Subsequent Command Bytes

All subsequent bytes which follow the above binary headers *must* have their MSB cleared to 0.

To cover cases where a value sent as part of a command must have the MSB set, we use the following escape codes:

- A hex byte  $7E_{16}$  causes the next byte received to have its MSB set upon receipt.
- A hex byte  $7F_{16}$  causes the next byte to be accepted without any further interpretation.

Thus, the byte  $C4_{16}$  is sent as the two-byte sequence  $7E\ 44$ , while a literal  $7E$  is sent as  $7F\ 7E$  and a literal  $7F$  as  $7F\ 7F$ .

If there is an error parsing or executing a command, the readerboard will ignore all subsequent input until a byte arrives with its MSB set to 1, whereupon it will expect to see the start of another command.

A few illustrative examples are shown in Table 2.1.

## Command Summary

The eight discrete LEDs are intended for a simple display of status information in a manner analogous to the Busylight project by the same author.<sup>2</sup> To support this usage, the F, S, X, \*, and ? commands are recognized in a manner compatible with how Busylight uses those same commands.

<sup>2</sup>See [github.com/MadScienceZone/busylight](https://github.com/MadScienceZone/busylight).



Input Sequence	Resulting Byte
00	00
7D	7D
7F 7E	7E
7F 7F	7F
7E 00	80
7E 01	81
7E 7D	FD
7E 7E	FE
7E 7F	FF

Table 2.1: Examples of RS-485 Escape Bytes.

These are categorized as “Busylight compatibility commands.” Unlike all other commands listed here, these are recognized regardless of case. Since the readerboard has a power supply capable of illuminating all of the status LEDs at once,<sup>3</sup> a new command L is added which allows any arbitrary pattern of steady LEDs to be turned on.

The remaining commands are used for management of the matrix display. All commands are summarized in Table 2.2.

Although the rev 2 hardware supports the ability to enable the RS-485 transmitter and send data back onto the network, this is not currently implemented by the firmware, and the intent is to have all devices listen passively to RS-485 traffic at all times.

## \*—Strobe Lights in Sequence

0	1	2	3	...	$n$	$n + 1$
*	$\langle led_0 \rangle$	$\langle led_1 \rangle$	$\langle led_2 \rangle$	...	$\langle led_{n-1} \rangle$	\$

/readerboard/v1/strobe?a= $\langle ad \rangle$ &l= $\langle led_0 \rangle \langle led_1 \rangle \dots \langle led_{n-1} \rangle$

Each  $\langle led \rangle$  value is an ASCII character corresponding to a discrete LED as shown in Table 2.9. An  $\langle led \rangle$  value of “\_” means there is no LED illuminated at that point in the sequence.

This command functions identically to the F command (see below), except that the lights are “strobed” (flashed very briefly with a pause between each light in the sequence).

<sup>3</sup>The Busylight cannot, since it is powered from the host computer’s USB port.

Message	Cmd	Description	Notes
strobe	*	Strobe LEDs in Sequence	[1]
	?	Query discrete LED status	[1] [2] [4]
flash	F	Flash LEDs in Sequence	[1]
light	L	Light one or more LEDs steady	[3]
light	S	Light one LED steady	[1]
off	X	All LEDs off	[1]
	^D	Abort/terminate command	
scroll	<	Scroll text across display	
	=	Set operational parameters	[4]
move	@	Move current column cursor	
font	A	Select character font	
clear	C	Clear matrix display	
graph	H	Add histogram/bargraph data point	
bitmap	I	Draw bitmap graphic image	
color	K	Set current color	
	Q	Query matrix display status	[2] [4]
text	T	Display text on display	

[1] Busylight compatible command

[2] Sends response (USB only)

[3] Busylight extension (not in original Busylight)

[4] USB only

Table 2.2: Summary of All Commands

## ←Scroll Text Across Display

0	1	2	...	n+1	n+2
<	<loop>	<string>			ESC

/readerboard/v1/scroll?a=<ad>&loop=<bool>&t=<string>

Displays the text <string> by scrolling it across the display from right to left. If <loop> is “.”, the text is only scrolled once; if it is “L” then it repeatedly scrolls across the screen in an endless loop.

The text is rendered in the current font and may contain any 8-bit bytes except as otherwise noted (but avoiding ASCII control codes is wise to be safe from conflict with future control codes which may be added to the protocol). The string is terminated by an escape character (hex byte 1B), indicated in the protocol description as ESC.

The string may include control codes as listed in Table 2.3.

Code	Hex	Description
^C<pos>	03<pos>	Move current column cursor to <pos>
^D	04	Never allowed in strings (command terminator)
^F<digit>	06<digit>	Switch current font
^H<pos>	08<pos>	Move cursor left <pos> columns
^K<rgb>	0B<rgb>	Change color to <rgb>
^L<pos>	0C<pos>	Move cursor right <pos> columns
^[	1B	Never allowed in strings (string terminator)

Table 2.3: Control Codes in String Values

## ==Set Operational Parameters

0	1	2	3	4
=	<ad>	<uspd>	<rspd>	<ad <sub>G</sub> >

This command sets a few operational parameters for the sign. Once set, these will be persistent across power cycles and reboots.

If the <ad> parameter is “\_” then the RS-485 interface is disabled entirely. Otherwise it is a value from 0–15 encoded as described in Table 2.5. This enables the RS-485 interface and assigns this sign’s address to <ad>.

The baud rate for the USB and RS-485 interfaces is set by the <uspd> and <rspd> values respectively. Each is encoded as per Table 2.4.

The <ad<sub>G</sub>> value is an address in the range 0–15 which is not assigned to any other device on the RS-485 network. This is used to signal that all readerboards should pay attention to the start of the command because it might target them either as part of a list of specific readerboards or because the command is intended for all readerboards at once. This is encoded in the same way as <ad>. If you only have one readerboard or do not wish to assign a global address, just set <ad<sub>G</sub>> to the same value as <ad>.

This command may only be sent over the USB port.

By default, an unconfigured readerboard is set to 9,600 baud with the RS-485 port disabled.

## ?—Query Discrete LED Status

0
?

This command causes the sign to send a status report back to the host to indicate what the discrete LEDs are currently showing. This response has the form:

Code	Speed
0	300
1	600
2	1,200
3	2,400
4	4,800
5	9,600 (default)
6	14,400
7	19,200
8	28,800
9	31,250
A	38,400
B	57,600
C	115,200

Table 2.4: Baud Rate Codes

0	1	2	3	4	5	6	7	8
L	$\langle led_0 \rangle$	$\langle led_1 \rangle$	$\langle led_2 \rangle$	$\langle led_3 \rangle$	$\langle led_4 \rangle$	$\langle led_5 \rangle$	$\dots$	$\langle led_{n-1} \rangle$
\$	F	flasher status (see below)						
\$	S	strober status (see below)						
\$	\n							

Each  $\langle led_x \rangle$  value is a single character which is “\_” if the corresponding LED is off, or the LED’s color code or position number if it is on. One such value is sent for each LED installed in the sign (typically eight for readerboards), followed by a “\$” to mark the end of the list.

The flasher and strober status values are variable-width fields which indicate the state of the flasher (see F command) and strober (see \* command) functions. In each case, if there is no defined sequence, the status field will be:

0	1
$\langle run \rangle$	-

Otherwise, the state of the flasher or strober unit is indicated by:

0	1	2	3	4	$\dots$	$n+3$
$\langle run \rangle$	$\langle pos \rangle$	@	$\langle led_0 \rangle$	$\langle led_1 \rangle$	$\dots$	$\langle led_{n-1} \rangle$

Value	Code	Value	Code
0–9	0–9	17–42	A–Z
10	:	43	[
11	;	44	\
12	<	45	]
13	=	46	^
14	>	47	_
15	?	48	`
16	@	49–63	a–o

(Each code is the numeric value plus 48.)

Table 2.5: ASCII Encoded Integer Values (0–63)

In either case,  $\langle run \rangle$  is the ASCII character “S” if the unit is stopped or “R” if it is currently running. If there is a defined sequence,  $\langle pos \rangle$  indicates the 0-origin position within the sequence of the light currently being flashed or strobed, encoded as described in Table 2.5. The  $\langle led_x \rangle$  values are as allowed for the F or \* command that set the sequence. (Regardless of the actual F or \* command parameters, the report will show symbolic color codes where possible, or numeric position codes otherwise.)

The status message sent to the host is terminated by a newline character (hex byte 0A), indicated in the protocol description above as “\n”.

This command may only be sent on the USB port.

## @—Set Column Cursor Position

0	1
@	$\langle pos \rangle$

/readerboard/v1/move?a= $\langle ad \rangle$ &pos= $\langle pos \rangle$

Sets the column cursor position to the value indicated by  $\langle pos \rangle$ . See Table 2.5.

## A—Select Font

0	1
A	$\langle digit \rangle$

/readerboard/v1/font?a= $\langle ad \rangle$ &idx= $\langle digit \rangle$

Sets the font to use for rendering text with the < and T commands. The font codes for  $\langle digit \rangle$  are listed in Table 2.6. The full text fonts support the printable ASCII characters plus a majority of the Unicode glyphs with codepoints less than 256. See Tables 2.7–2.8 for a complete font glyph listing with codepoint assignments.

Code	Font Description
0	Fixed-width 5×7 matrix plus descenders in 8th row
1	Variable-width version of font 0
2	Bold alphanumerics and special symbols

Table 2.6: Font Codes

	0	1	2	3	4	5	6	7	
00x				move	end		font		0x
01x	back			color	forw				
02x									1x
03x				esc					
04x		!	"	#	\$	%	&	'	2x
05x	(	)	*	+	,	-	.	/	
06x	0	1	2	3	4	5	6	7	3x
07x	8	9	:	;	<	=	>	?	
10x	@	A	B	C	D	E	F	G	4x
11x	H	I	J	K	L	M	N	O	
12x	P	Q	R	S	T	U	V	W	5x
13x	X	Y	Z	[	\	]	^	_	
14x	'	a	b	c	d	e	f	g	6x
15x	h	i	j	k	l	m	n	o	
16x	p	q	r	s	t	u	v	w	7x
17x	x	y	z	{		}	~	///	
20x	“	”	‘	’	†	‡	...	'	8x
21x	”	!!	—	←	→	↑	↓	≠	
22x	≤	≥	≈	Γ	Δ	Ξ	Π	Σ	9x
23x	Ω	π	ρ	σ	—	‰			
24x		ı	¢	£	¤	¥	¦	§	Ax
25x		©	ª	«	¬	-	®		
26x	°	±	²	³		μ	¶	•	Bx
27x		¹	º	»	¼	½	¾	¿	
30x	À	Á	Â	Ã	Ä	Å	Æ	Ç	Cx
31x	È	É	Ê	Ë	Ì	Í	Î	Ï	
32x	Ð	Ñ	Ò	Ó	Ô	Õ	Ö	×	Dx
33x	Ø	Ù	Ú	Û	Ü	Ý	Þ	ß	
34x	à	á	â	ã	ä	å	æ	ç	Ex
35x	è	é	ê	ë	ì	í	î	ï	
36x	ð	ñ	ò	ó	ô	õ	ö	÷	Fx
37x	ø	ù	ú	û	ü	ý	þ	ÿ	
	8	9	A	B	C	D	E	F	

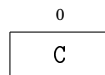
Table 2.7: Font Table for Fonts #0 and #1

	0	1	2	3	4	5	6	7	
00x				move	end		font		0x
01x	back			color	forw				
02x									1x
03x				esc					
04x		!	□	■					2x
05x					,		.		
06x	0	1	2	3	4	5	6	7	3x
07x	8	9							
10x	©	A	B	C	D	E	F	G	4x
11x	H	I	J	K	L	M	N	O	
12x	P	Q	R	S	T	U	V	W	5x
13x	X	Y	Z						
14x		←	→	↑	↓	↖	↗	↘	6x
15x	✓	←	→	↑	↓	■	■		
16x	✓	✓	∞	Œ	œ	€	∴	∴	7x
17x	✕	◀	▶	▲	▼	↕	◆	◇	
20x	λ	Θ	Φ	Ψ					8x
21x									
22x	AM	PM	°F	°C					9x
23x	NM	WC	1Q	WG	FM	WG	3Q	WC	
24x		TS1	TS2	TS3	TS4	TS5	TS6	TS7	Ax
25x	TS8								
	8	9	A	B	C	D	E	F	

TS(*n*) = Thin space of *n* pixels

Table 2.8: Font Table for Font #2

## C—Clear Matrix Display



/readerboard/v1/clear?a=<ad>

Clears the matrix display so that no LEDs are illuminated. Does not affect the discrete LEDs.

## F—Flash Lights in Sequence

0	1	2	3	...	<i>n</i>	<i>n</i> + 1
F	<led <sub>0</sub> >	<led <sub>1</sub> >	<led <sub>2</sub> >	...	<led <sub><i>n</i>-1</sub> >	\$

/readerboard/v1/flash?a=<ad>&l=<led<sub>0</sub>><led<sub>1</sub>><led<sub>2</sub>>...<led<sub>*n*-1</sub>>





```
/readerboard/v1/graph?a=<ad>&v=<n>&colors=<rgb_0><rgb_1><rgb_2><rgb_3>
<rgb_4><rgb_5><rgb_6><rgb_7>
```

This command is used to draw a bar-graph element. Repeating this command causes a scrolling data display which shows a set of data samples over some period of time.

In the simplest form, it takes a single byte parameter. The value  $\langle n \rangle$  is an ASCII digit character in the range “0”–“8”, and is drawn in the far-right column of the matrix display, as a column of  $\langle n \rangle$  lights stacked up from the bottom row (a value of 0 results in no lights, up to 8 which is a full column of eight lights; a value of 9 is treated as if it were 8). All existing matrix data are scrolled left one column.

In the second form, it takes eight  $\langle rgb \rangle$  values (q.v.) which give the color to light up each row in the bar-graph column.

In HTTP, the value of  $\langle n \rangle$  is sent as an integer value.

## I—Draw Bitmap Image

0	1	2	3	4	5	6	7
I	$\langle merge \rangle$	$\langle pos \rangle$	$\langle trans \rangle$	$\langle R coldata_0 \rangle$	$\langle R coldata_1 \rangle$	...	
$\langle R coldata_{n-1} \rangle$	\$	$\langle G coldata \rangle \dots$	\$	$\langle B coldata \rangle \dots$	\$		

```
/readerboard/v1/bitmap?a=<ad>&merge=<bool>&pos=<pos>
&trans=<trans>&image=<R coldata>...$<G coldata>...$<B coldata>...
```

Draws an arbitrary bitmap image onto the matrix display starting at column  $\langle pos \rangle$ , encoded as per Table 2.5. A  $\langle pos \rangle$  value of “~” represents the current column cursor position.

Each column data, from left to right, are given by  $\langle coldata \rangle$  values, each of which is a two-digit ASCII hexadecimal value with the least-significant bit representing the top row of the matrix.

The column data values are terminated by either a dollar-sign (“\$”) character or the escape control character (hex byte 1B), indicated in the protocol diagram above simply as “\$”.

The first set of column data provide the bits for the red color plane. After the terminating byte, two more sets of column data are sent, each with identical format to the first, to provide the bits for the green and blue color planes, respectively.

The column cursor is moved to be after the end of the image.

If  $\langle merge \rangle$  is the character “.” then each column’s contents is cleared before setting the pixels as per the  $\langle coldata \rangle$  value. If  $\langle merge \rangle$  is “M” the bits set in  $\langle coldata \rangle$  are added to the lit pixels already in the column.

The  $\langle trans \rangle$  value indicates the transition effect to use when adding the image to the display. See Table 2.10.

Code	Transition
.	No transition
>	Scroll in from left
<	Scroll in from right
^	Scroll up from bottom
v	Scroll down from top
L	wipe left
R	wipe right
U	wipe up
D	wipe down
	wipe left and right from middle column
-	wipe up and down from middle row
?	choose a random transition

Table 2.10: Transition Effect Codes

Code	Color
0	black
1	red
2	green
3	yellow
4	blue
5	magenta
6	cyan
7	white

Table 2.11: Color codes for  $\langle rgb \rangle$  parameters**K—Set Current Color**

0	1
K	$\langle rgb \rangle$

`/readerboard/v1/color?a= $\langle ad \rangle$ &color= $\langle rgb \rangle$`

This command sets the color which all future commands will use by default (although some of them allow for the specification of colors directly on an *ad hoc* basis, which does not affect the current default color).

The  $\langle rgb \rangle$  value is a digit in the range 0–7, with the meanings defined in Table 2.11. Note that anything drawn in black simply turns off the corresponding pixels.

**L—Light Multiple LEDs**

0	1	2	3	...	$n$	$n + 1$
L	$\langle led_0 \rangle$	$\langle led_1 \rangle$	$\langle led_2 \rangle$	$\cdots$	$\langle led_{n-1} \rangle$	\$

/readerboard/v1/light?a= $\langle ad \rangle$ &l= $\langle led_0 \rangle \langle led_1 \rangle \langle led_2 \rangle \cdots \langle led_{n-1} \rangle$

This command is identical to the S command (see below), except that multiple discrete LEDs can be specified, all of which are illuminated simultaneously. See Table 2.9. Note that if a strobe sequence is running (via a previous \* command), it remains running.

The list of  $\langle led \rangle$  values is terminated by either a dollar sign (\$) character or an escape byte (hex value 1B), represented in the protocol diagram as “\$”.

**Q—Query Readerboard Status**

0
Q

This command causes the sign to send a status report back to the host to indicate the general status of the device except for the discrete LED display which may be queried using the ? command. The response has the form:

0	1	2	3	4	5	6	7	8
Q	$\langle model \rangle$	=	$\langle ad \rangle$	$\langle uspd \rangle$	$\langle rspd \rangle$	$\langle ad_G \rangle$	\$	V
$\langle hwversion \rangle$	\$	R	$\langle romversion \rangle$	\$	S	$\langle serial \rangle$		
\$	M	$\langle R coldata_0 \rangle$	$\langle R coldata_1 \rangle$	$\cdots$	$\langle R coldata_{63} \rangle$			
\$	$\langle G coldata_0 \rangle$	$\langle G coldata_1 \rangle$	$\cdots$	$\langle G coldata_{63} \rangle$	\$			
$\langle B coldata_0 \rangle$	$\langle B coldata_1 \rangle$	$\cdots$	$\langle B coldata_{63} \rangle$	\n				

The  $\langle model \rangle$  field may be “L” for the legacy hardware the author still has lying around (but this shouldn’t be something anyone else would need to see), “M” for the current 64×8 matrix display hardware, or “C” for 64×8 RGB color display boards.

$\langle hwversion \rangle$  and  $\langle romversion \rangle$  indicate the versions, respectively, of the hardware the firmware was compiled to drive, and of the firmware itself. Each of these fields are variable-width and conform to the semantic version standard 2.0.0.<sup>4</sup> Each is terminated by a dollar-sign (\$) character (and thus those strings may not contain dollar signs).

<sup>4</sup>See [semver.org](http://semver.org).

The  $\langle serial \rangle$  field is a variable-width alphanumeric string which was set when the firmware was compiled. It should be a unique serial number for the device (although that depends on some effort on the part of the person compiling the firmware to insert that serial number each time). Serial numbers 0–299 are reserved for the original author’s use. This string is also terminated with a dollar sign.

The  $\langle coldata \rangle$  bytes are sent just as with the I command, as hexadecimal values indicating the LEDs lit on the matrix display, with  $\langle coldata_0 \rangle$  being the leftmost column of the display and  $\langle coldata_{63} \rangle$  being the rightmost. In each column, the least significant bit indicates the LED on the top row.

The  $\langle ad \rangle$ ,  $\langle uspd \rangle$ , and  $\langle rspd \rangle$  values are as last set by the = command (or the factory defaults if they were never changed).

The status message sent to the host is terminated by a newline character (hex byte 0A), indicated in the protocol description above as “\n”.

### Busylight Device Query Response

If a dedicated (non-readerboard) busylight device is sent the Q command, it responds with the following information.

0	1	2	3	4	5	6	7	8
Q	B	=	$\langle ad \rangle$	$\langle uspd \rangle$	$\langle rspd \rangle$	$\langle ad_G \rangle$	\$	V
$\langle hwversion \rangle$		\$	R	$\langle romversion \rangle$		\$	S	$\langle serial \rangle$
\$	\n							

### S—Light Single LED

0	1
S	$\langle led \rangle$

/readerboard/v1/light?a= $\langle ad \rangle$ &l= $\langle led \rangle$

Stops the flasher (cancelling any previous F command) and turns off all discrete LEDs. The single LED indicated by  $\langle led \rangle$  is turned on. See Table 2.9. Note that if a strobe sequence is running (via a previous \* command), it remains running.

This command may be given in upper- or lower-case (“s” or “S”).

### T—Display Text

0	1	2	3	4	...	n+4
T	$\langle merge \rangle$	$\langle align \rangle$	$\langle trans \rangle$	$\langle string \rangle$		ESC

/readerboard/v1/text?a= $\langle ad \rangle$ &merge= $\langle bool \rangle$

`&align=<align>&trans=<trans>&t=<string>`

Displays the text *<string>* at the current cursor position. The cursor position is then moved past the text to be ready for the next string to be printed.

The *<align>* code indicates how the text is aligned on the display (TBD).

The *<trans>* code specifies the transition effect to be used to add this string to the display as shown in Table 2.10.

The text is rendered in the current font and may contain any 8-bit bytes except as otherwise noted (but avoiding ASCII control codes is wise to be safe from conflict with future control codes which may be added to the protocol). The string is terminated by an escape character (hex byte 1B), indicated in the protocol description as ESC. (Since a dollar sign may appear in *<string>*, the terminator must be an escape character for this command.)

The string may include control codes as listed in Table 2.3.

## X—Turn off Discrete LEDs

0  

X

  
`/readerboard/v1/off?a=<ad>`

Turns off the flasher, strober, and all discrete LEDs.

This command may be given in upper- or lower-case (“x” or “X”).



## SERVER-ONLY COMMANDS

The enjoyment of one's tools is  
an essential ingredient of  
successful work.

—Donald E. Knuth

**F**OR THE MOST PART the server exists as a way to host readerboards and busylights from a central machine while allowing users on other networked machines to post messages to them. One shortcoming of this approach is that although *access* to the devices is made widely available, *coordination* between the users wishing to place content on display is not provided. Each update totally changes the state of the target devices.

This chapter describes server-side coordination between users in a network environment by providing a set of commands which clients can post to the server to request information to be displayed for them alongside other content other users have posted. It also provides some services to keep boards updated with information known to the server which the devices don't themselves track, such as time of day.

### post—Post a Message to the Displays

```
/readerboard/v1/post?a=<ad>&t=<text>&id=<id>&trans=<trans>
&until=<datetime>&hold=<duration>&color=<rgb>&repeat=<schedule>
```

Adds a text message to the display list. The message may include the special tokens listed in Table 3.1. The server will maintain the list of posted images and will update the devices as needed to display dynamic content.

Code	Description
{big}	Display letters and numbers in large font
{date}	Date as “ <i>&lt;dd&gt;-&lt;mmm&gt;-&lt;yyyy&gt;</i> ”
{normal}	Stop displaying numbers in large font
{mdy}	Date as “ <i>&lt;mm&gt;/&lt;dd&gt;/&lt;yyyy&gt;</i> ”
{pom}	Phase of the moon (as a symbol)
{time12}	Time as “ <i>&lt;hh&gt;:&lt;mm&gt;</i> AM/PM” on 12-hour clock
{time24}	Time as “ <i>&lt;hh&gt;:&lt;mm&gt;</i> ” on 24-hour clock
{ymd}	Date as “ <i>&lt;yyyy&gt;-&lt;mm&gt;-&lt;dd&gt;</i> ”
{ <i>\$&lt;name&gt;</i> }	User variable <i>&lt;name&gt;</i>
{ {	Literal “{”
} }	Literal “}”

Table 3.1: Special Codes in Post Messages

If any lower-level display matrix commands are received that directly manipulate the matrix, the display of posted messages is suspended in favor of the directly set content. When a `clear` command is received, then display of the posted message list will resume.

The *<id>* value must be unique but the server doesn’t assign these in order to keep the API simple. Thus, it is recommended that you assign these as UUIDs or other scheme to keep them from colliding.

If `trans` is given, this message will be introduced using the specified transition effect.

If `until` is given, the message will automatically unpost when the specified date and time is reached.

If `hold` is given, the message will remain on-screen for the specified time duration before moving on to the next posted message.

If `color` is given, the current color will be changed to the specified value before writing the message; otherwise (or additionally) color codes may be added in-line in the message text.

If `repeat` is given, *<schedule>* specifies (in a way yet to be determined) a repeating display schedule for this message (e.g., display this every hour on the hour).

### unpost—Remove a Posted Message

`/readerboard/v1/unpost?a=<ad>&id=<id>`

Remove the message with the given *<id>* from the display list.

### update—Update Dynamic Content

`/readerboard/v1/update?<name0>=<value0>&<name1>=<value1>...`



For each *⟨name⟩* and *⟨value⟩* pair, define or update the corresponding user variable (usable in posted messages as `{${⟨name⟩}}`). The updated value will be displayed from this point until it is updated again.



## PINOUTS

No cord or cable can draw so  
forcibly, or bind so fast, as love  
can do with a single thread.

—Robert Burton

**T**HIS CHAPTER DESCRIBES each connector used by the readerboard devices and what signals are present on which pins.

### Connectors for Version 3.1.0 Boards

#### Arduino Bus Connectors [3.1.0 J0]

Two parallel rows of stacking pins, for a total of 50 pins, extend out of the back of the readerboard PCB. An Arduino Mega 2560 or Due microcontroller board is connected to these pins.

The USB connector on the Arduino board may be used to directly connect the readerboard to a PC for initial configuration and/or to use it as a directly-connected singleton device. (If there are multiple devices in use, it may be preferable to switch to the RS-485 network after initial configuration of the device.)

#### Power / RS-485 (8-pin terminal) [3.1.0 J1]

The single external connector on version 2.1.0 boards is an 8-pin screw terminal block. This accepts a +9 V DC power input and ground on pins 3 and 4 respectively, which powers the entire board and the attached Arduino

controller. If RS-485 communications will be used, the incoming signal is received on pins 1, 2, and 5 while the outgoing signal is on pins 6, 7, and 8. (In actuality, the “input” and “output” sense is arbitrary and either set of A and B signals may be used as input or output.)

If this device is the last in the RS-485 network chain, insert a  $120\Omega$  resistor between the A and B terminals that would have been used as the output if there had been another device connected there. This properly terminates the RS-485 network at that point.

1	A (Data in +)	5	GND
2	B (Data in −)	6	GND
3	+9 V DC in	7	A (Data out +)
4	GND	8	B (Data out −)

## Connectors for Legacy Boards

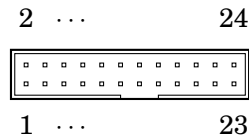
### Connectors for Version 2.1.0 Boards

#### Power / RS-485 (8-pin terminal) [2.1.0 J0]

This is wired the same as J1 on the 3.1.0 boards.

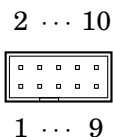
### Earlier Boards

#### Matrix Control (24-pin ribbon cable) [1.0.1 J1, 2.0.0 J1]



For readerboards before version 2.1.0, this 24-position ribbon cable carries signals to directly drive the  $64 \times 8$  LED matrix. The other end of this cable mates with J0 on the shield board. The pinout of its IDC header is:

1	D6	7	RCLK	13	+5 V DC	19	Gnd
2	D5	8	D2	14	+5 V DC	20	Gnd
3	D7	9	$\overline{G}$	15	+5 V DC	21	R2
4	D4	10	D1	16	+5 V DC	22	REN
5	SRCLK	11	$\overline{SRCLR}$	17	Gnd	23	R1
6	D3	12	D0	18	Gnd	24	R0

**Discrete LEDs (10-pin ribbon cable) [1.0.1 J2, 2.0.0 J2]**

For readerboards before version 2.1.0, this 10-position ribbon cable carries signals to directly drive the  $64 \times 8$  LED matrix. The other end of the cable mates with J1 on the shield board. The pinout of its IDC header is:

1	GND	6	L6
2	GND	7	L2
3	L0	8	L5
4	L7	9	L3
5	L1	10	L4

**Board Power (3-pin screw terminal) [1.0.1 J0, 2.0.0 J0]**

This 3-position screw terminal block provides power to the readerboard. Note that the +5 V supply is also connected to pins 13–16, and Ground to pins 17–20 of J1, the only power required here is the +9 V input that drives the LEDs themselves.

1	+5 V DC in
2	GND
3	+9 V DC in

**Shield Power (5-pin screw terminal) [Shield J2]**

This 5-position screw terminal block accepts incoming +9 V DC power and ground on pins 4 and 3 respectively. It then provides +5 V DC, +9 V DC, and ground outputs on pins 1, 2, and 5 respectively to supply power to the main display board.

1	+5 V DC out
2	GND
3	GND
4	+9 V DC in
5	+9 V DC out

**Shield RS-485 (6-pin screw terminal) [Shield J4]**

This 6-position screw terminal block accepts incoming RS-485 signals A, B, and ground on pins 2, 1, and 3 respectively, and outputs the network signals A, B, and ground on pins 6, 5, and 4 respectively, to go on to the next device in the chain. If this is the last device, then nothing should be

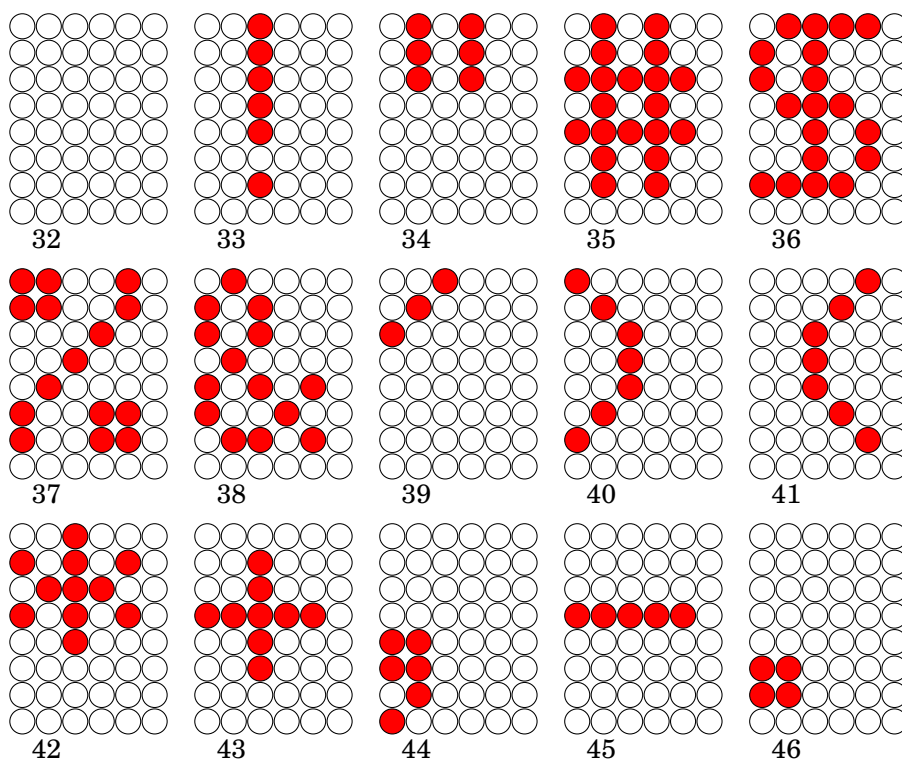
connected to pins 5 and 6. Instead, install jumper J5 which connects a  $120\Omega$  resistor across those terminals to terminate the network at that point.

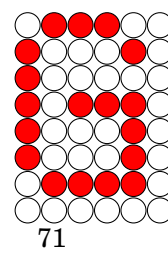
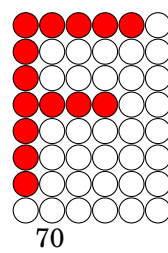
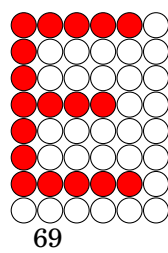
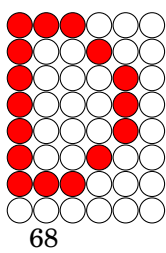
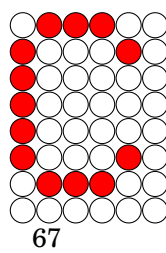
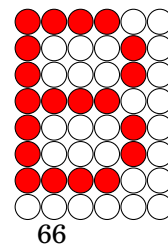
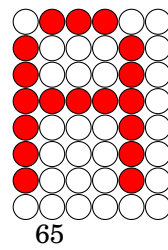
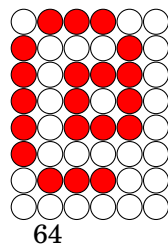
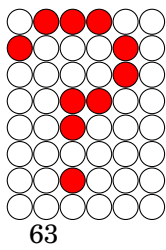
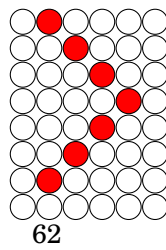
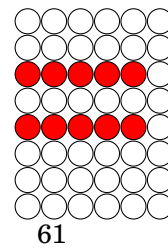
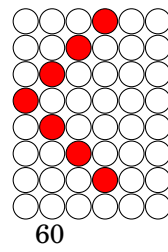
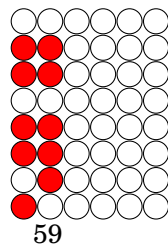
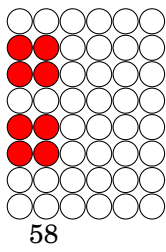
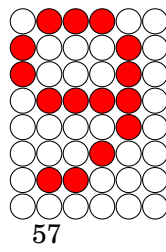
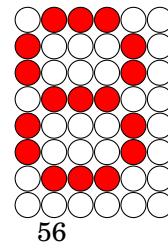
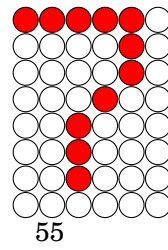
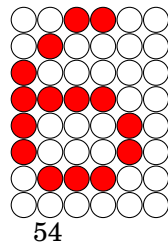
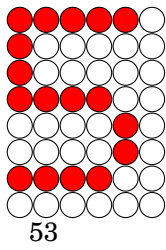
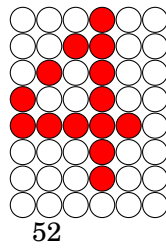
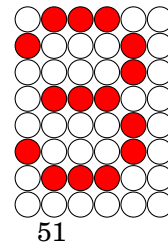
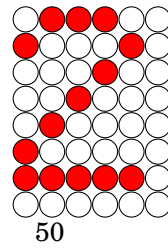
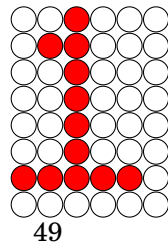
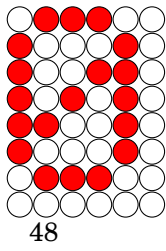
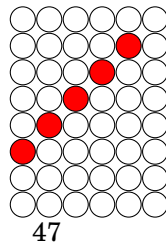
- 1 B (Data In -)
- 2 A (Data In +)
- 3 GND
- 4 GND
- 5 B (Data Out -)
- 6 A (Data Out +)

CHAPTER 5

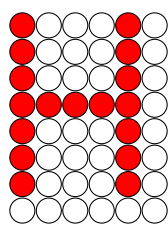
# FONT GLYPHS

## Font 0

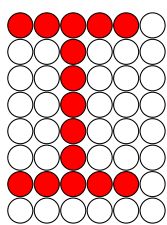




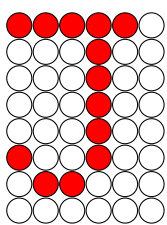




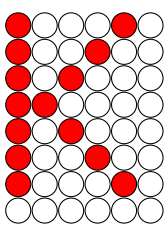
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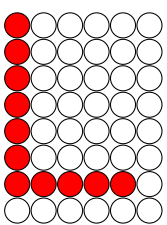
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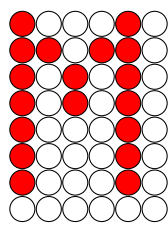
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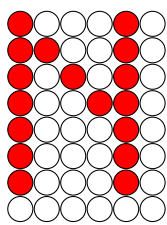
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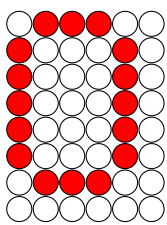
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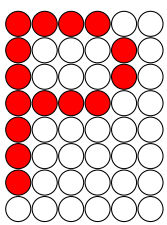
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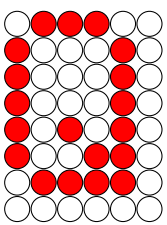
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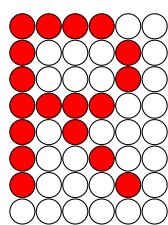
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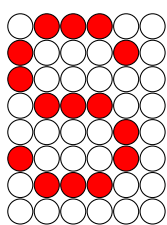
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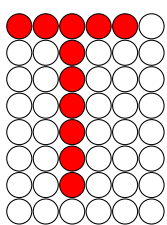
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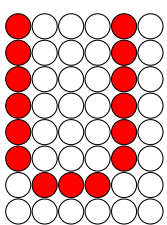
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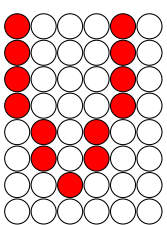
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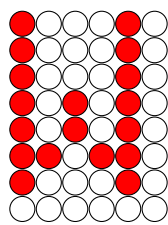
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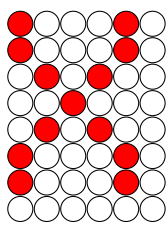
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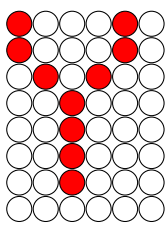
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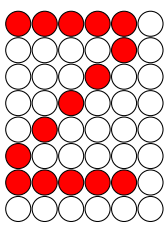
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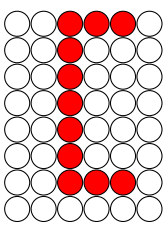
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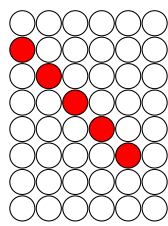
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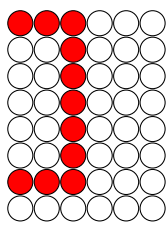
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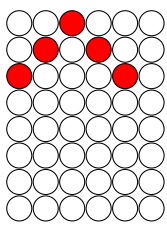
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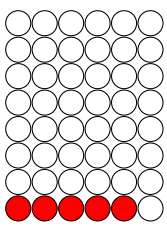
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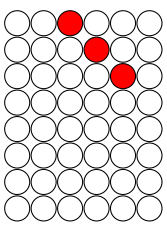
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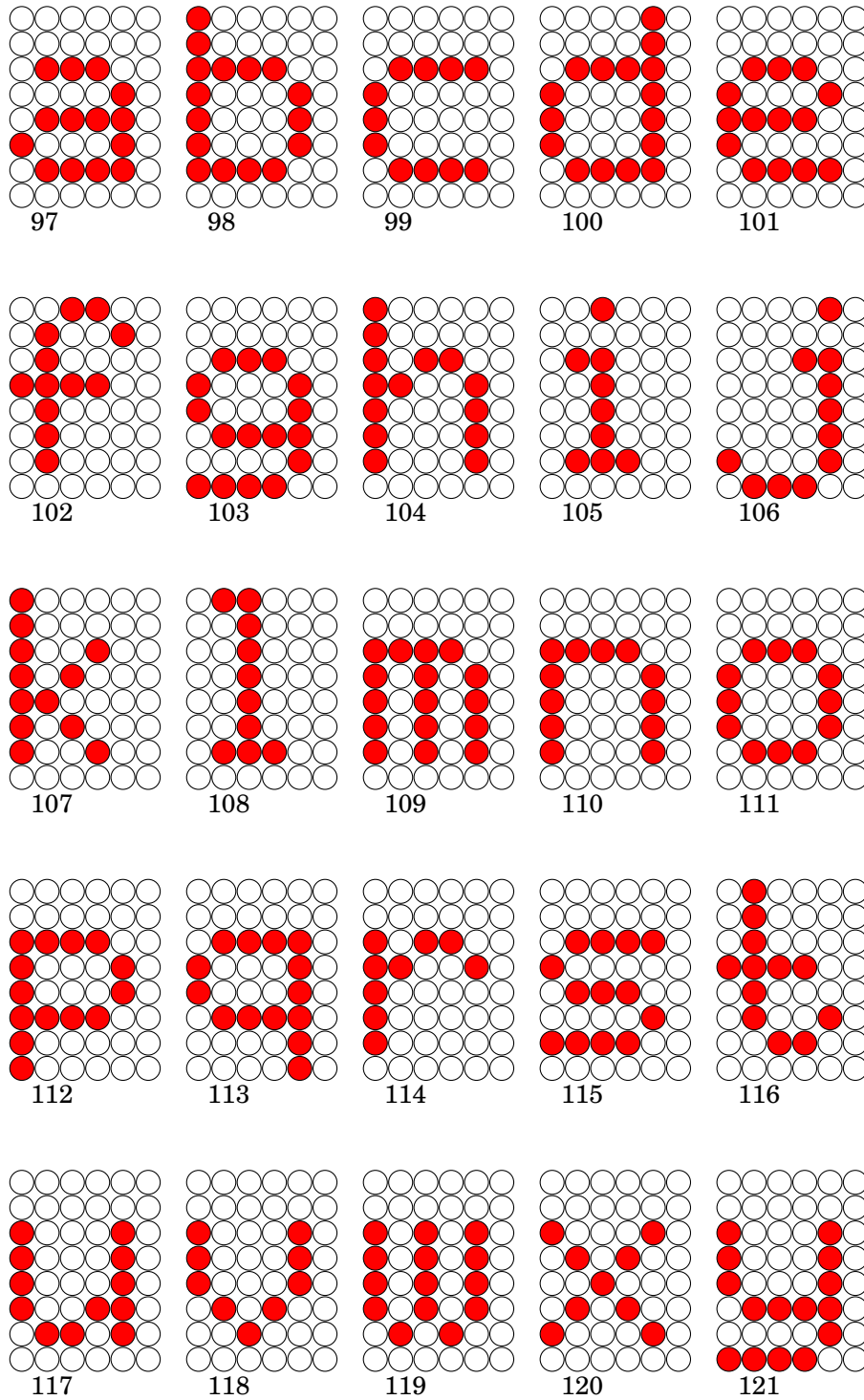
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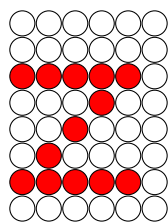


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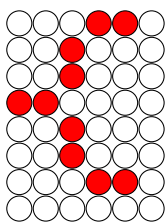


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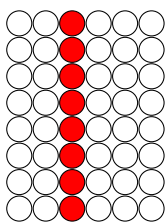




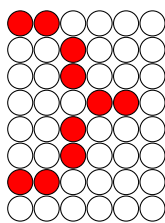
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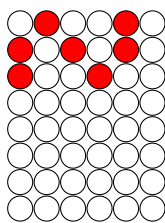
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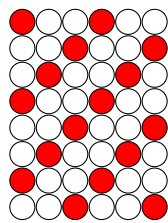
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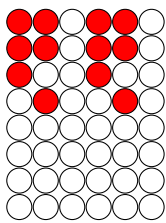
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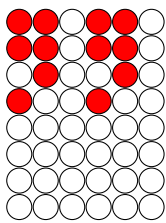
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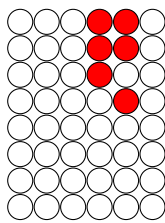
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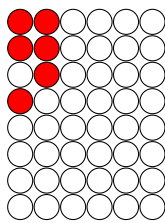
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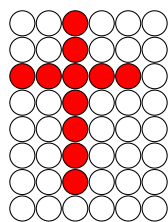
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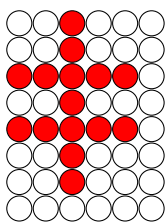
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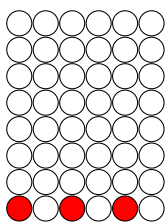
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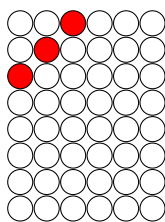
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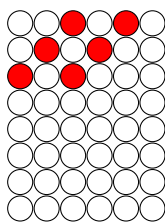
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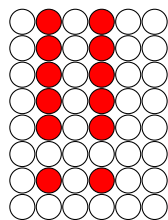
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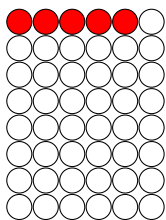
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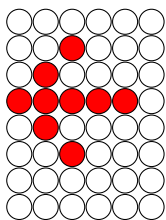
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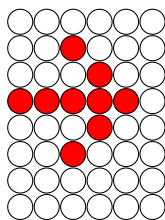
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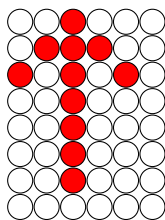
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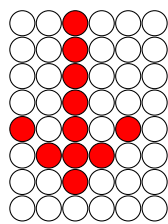
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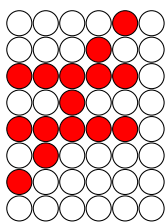
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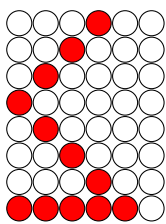
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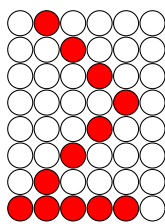
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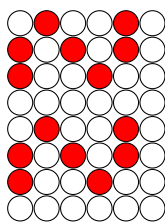
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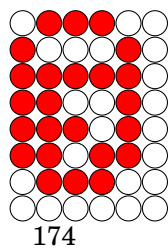
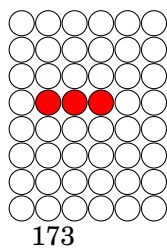
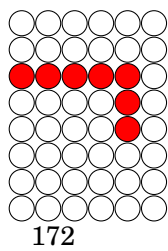
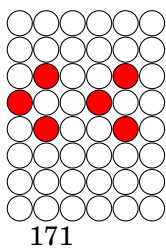
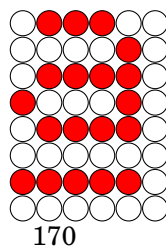
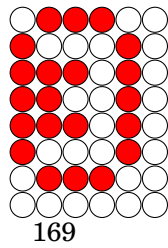
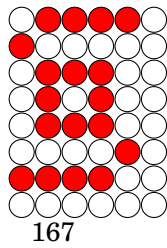
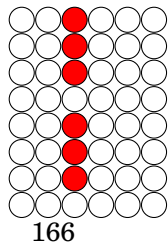
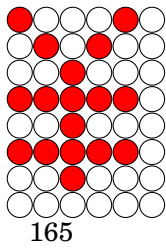
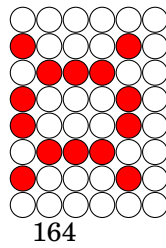
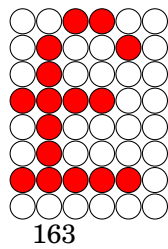
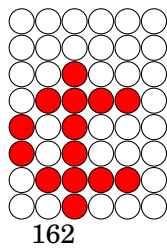
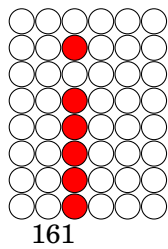
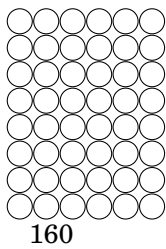
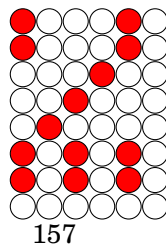
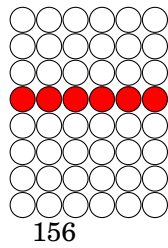
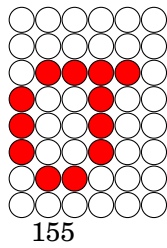
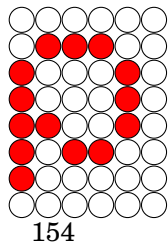
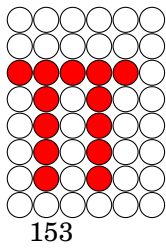
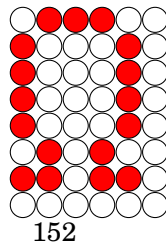
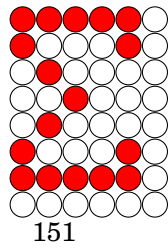
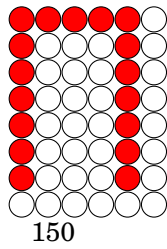
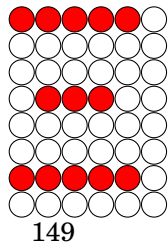
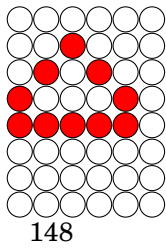
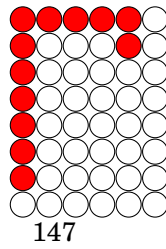
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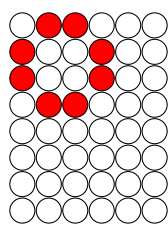


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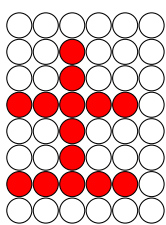


146

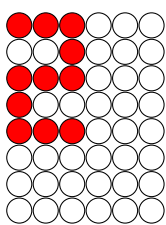




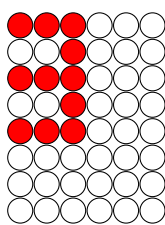
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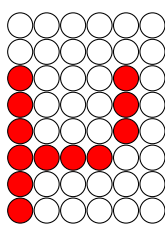
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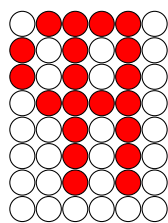
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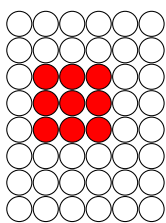
179



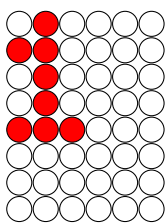
181



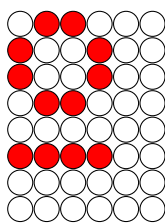
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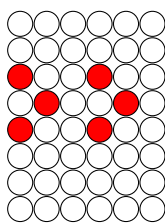
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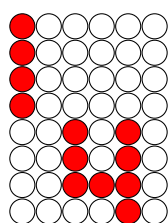
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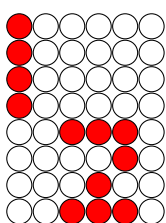
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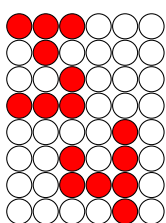
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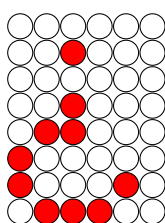
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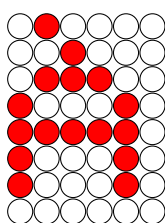
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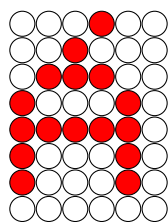
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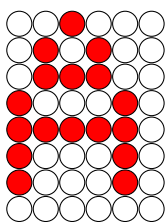
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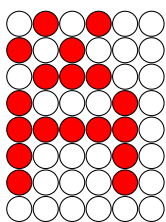
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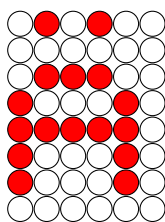
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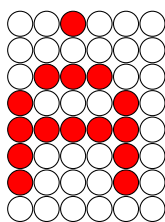
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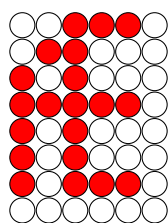
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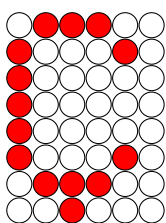
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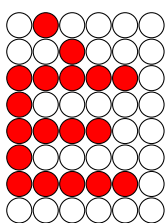
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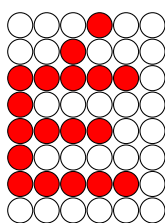
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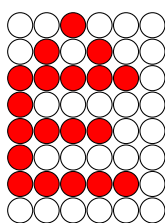
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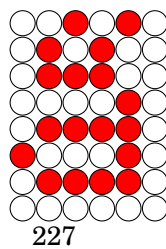
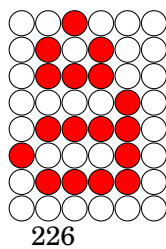
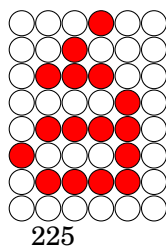
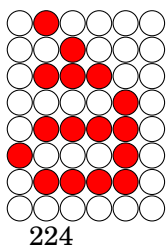
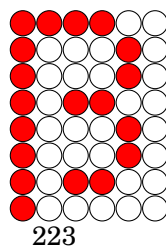
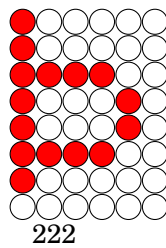
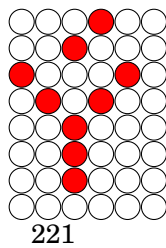
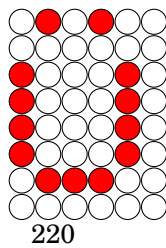
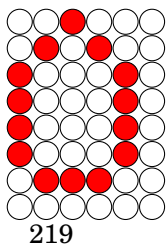
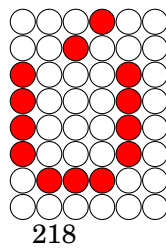
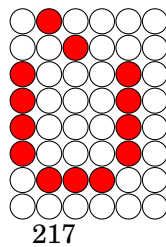
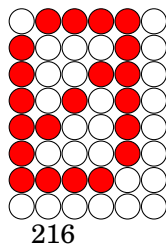
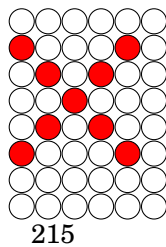
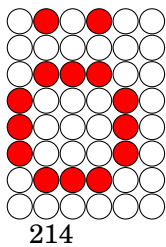
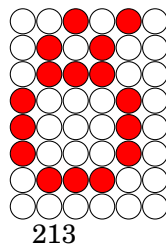
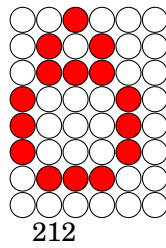
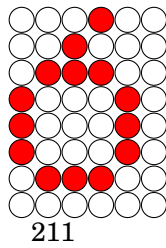
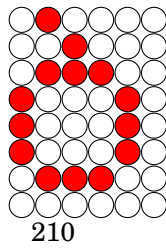
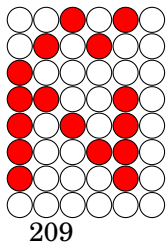
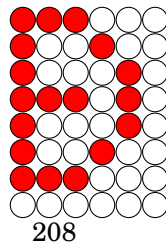
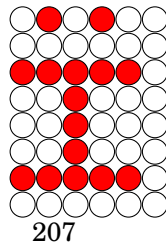
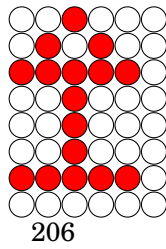
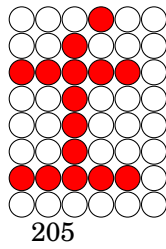
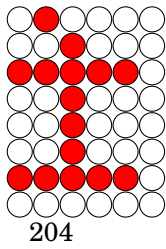
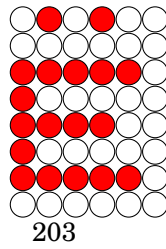
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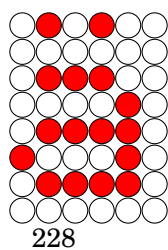
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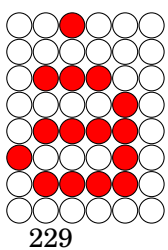
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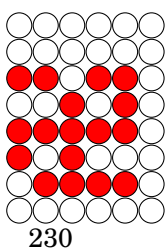




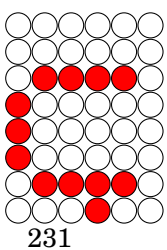
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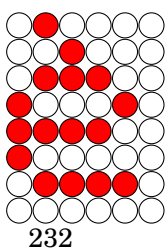
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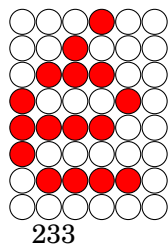
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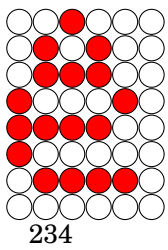
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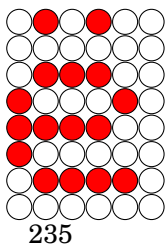
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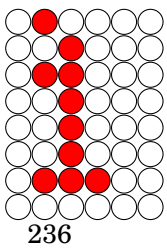
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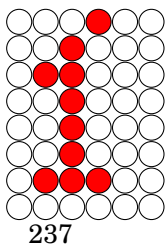
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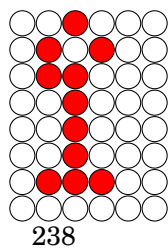
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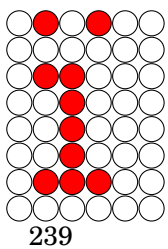
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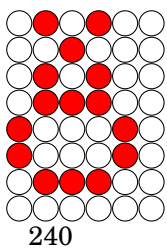
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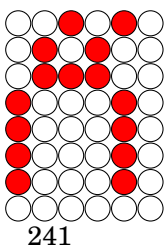
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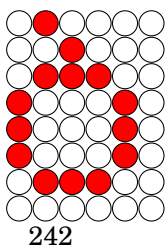
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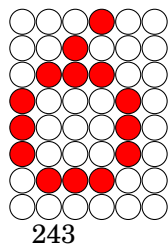
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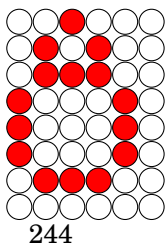
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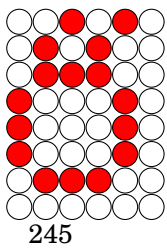
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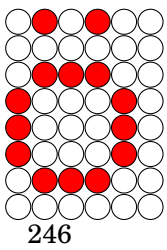
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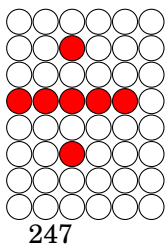
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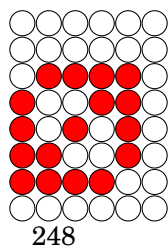
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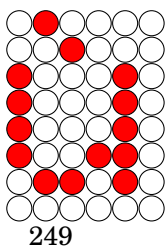
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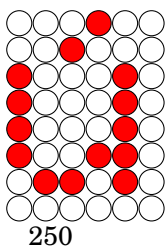
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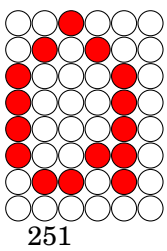
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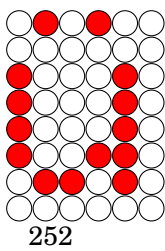
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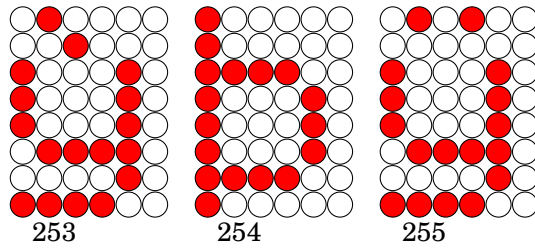
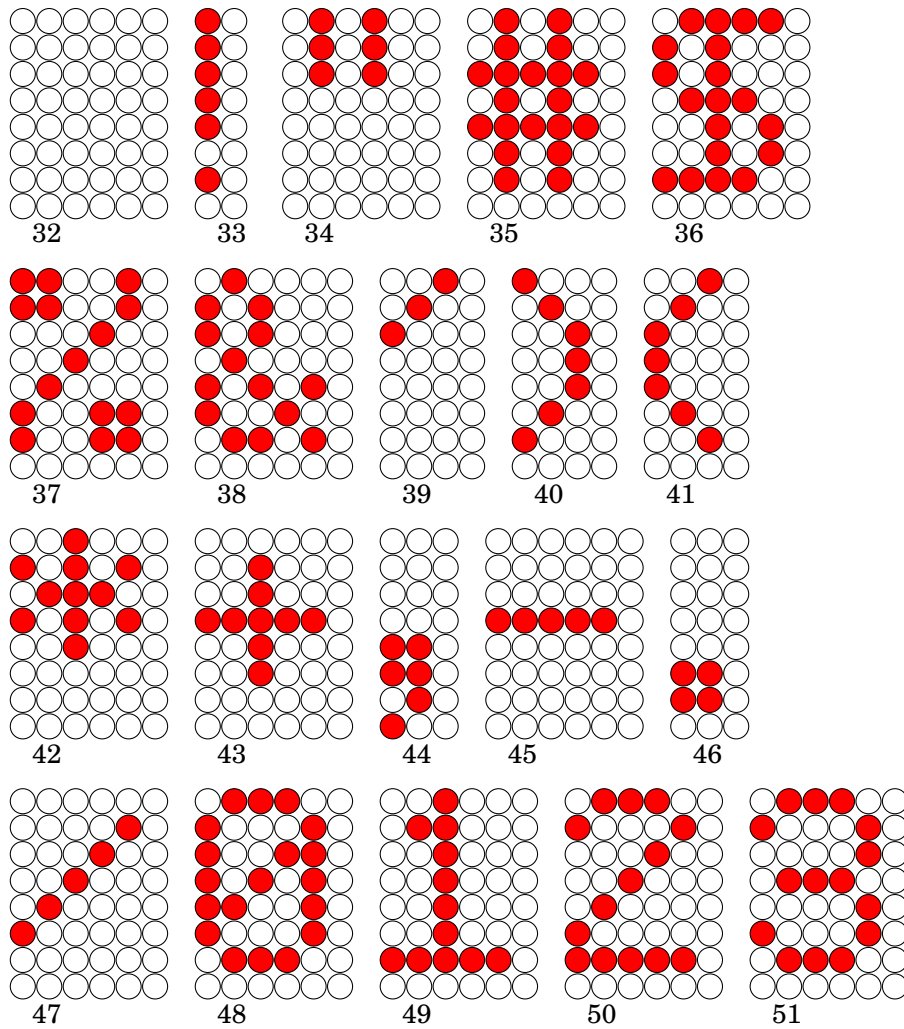
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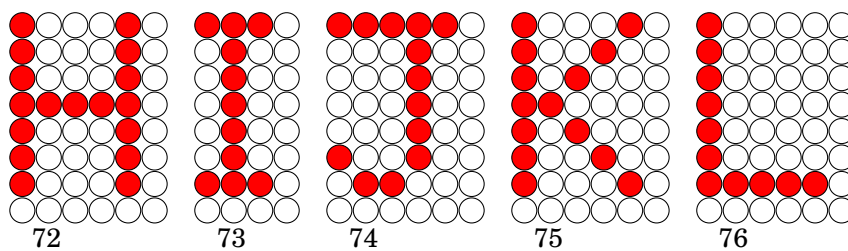
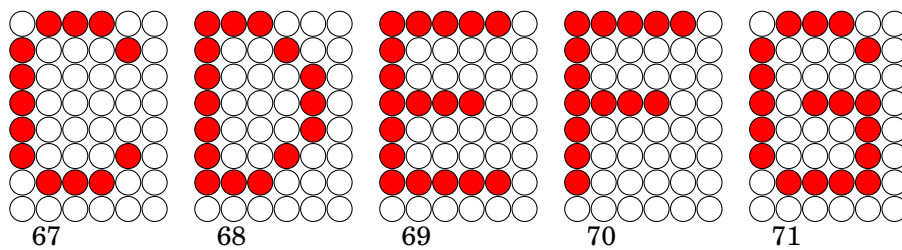
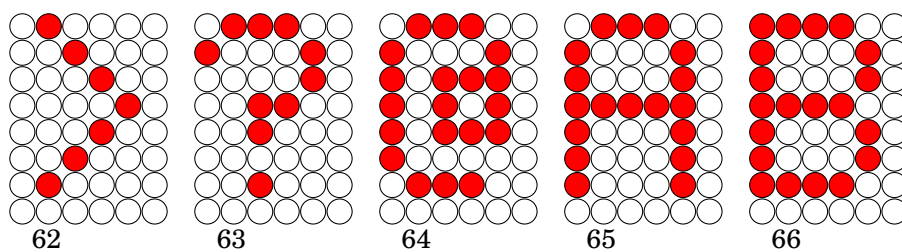
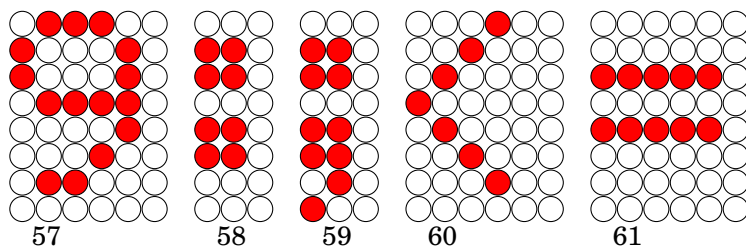
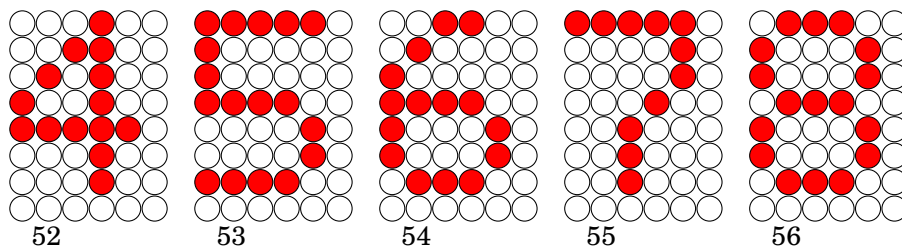
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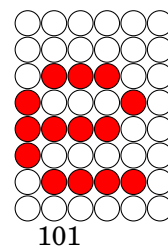
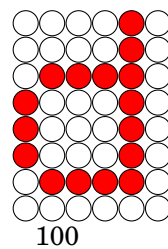
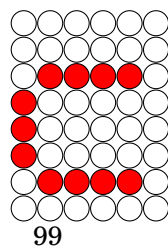
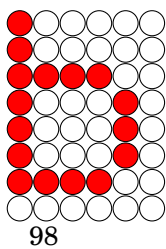
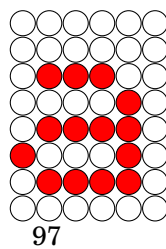
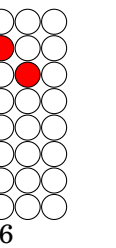
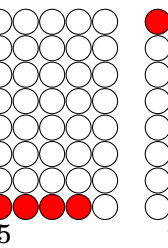
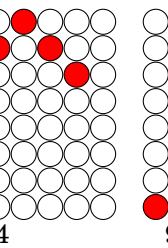
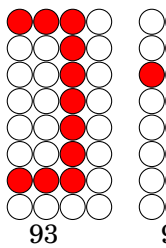
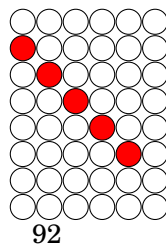
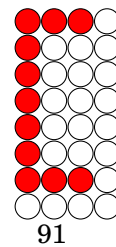
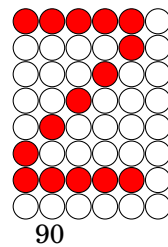
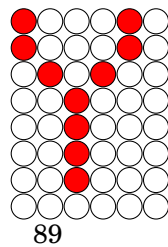
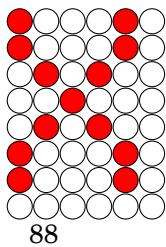
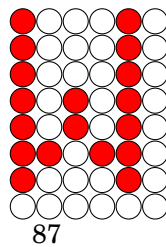
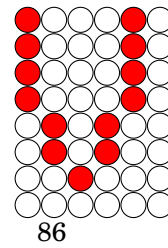
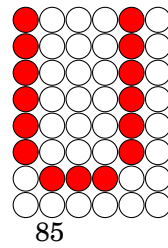
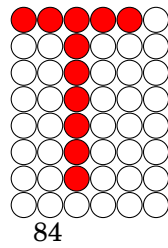
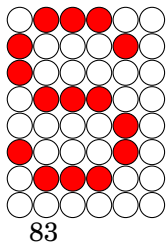
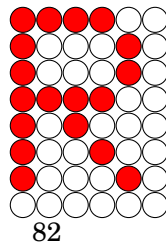
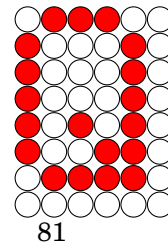
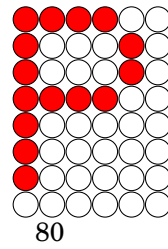
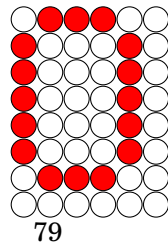
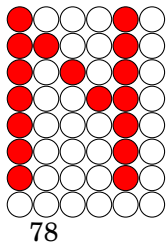
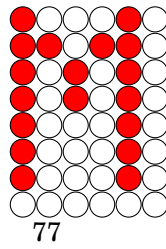


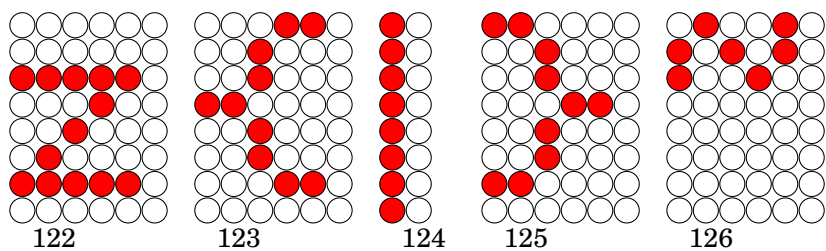
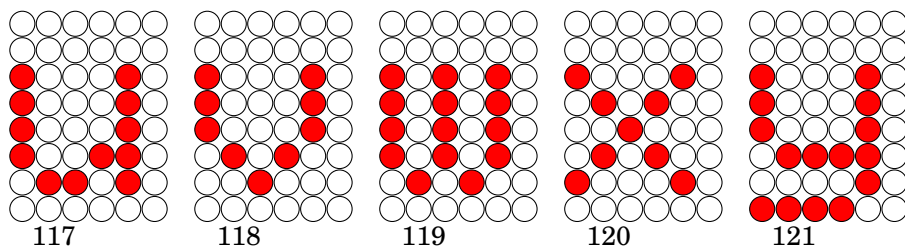
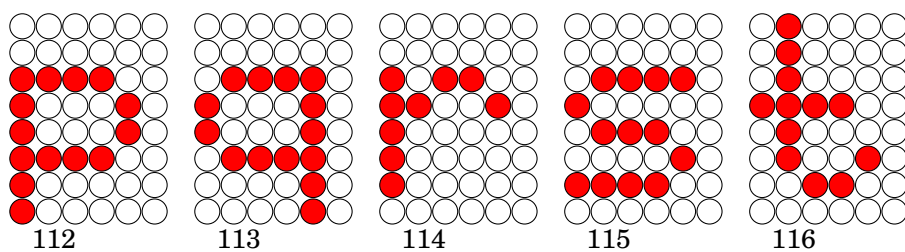
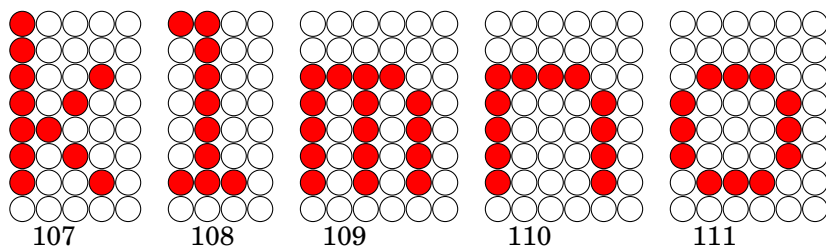
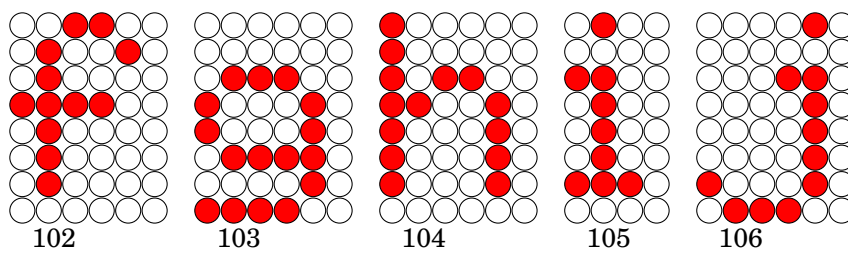
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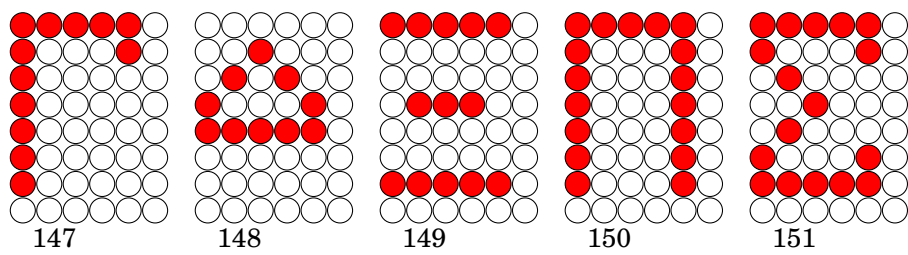
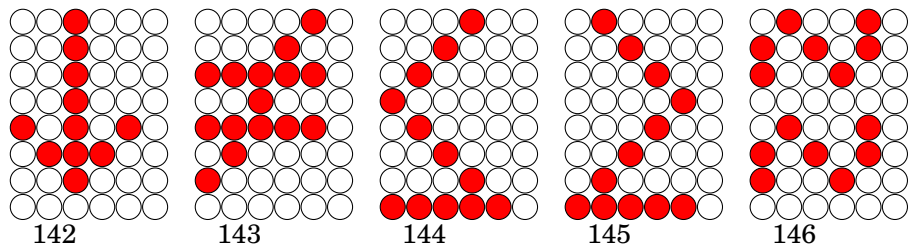
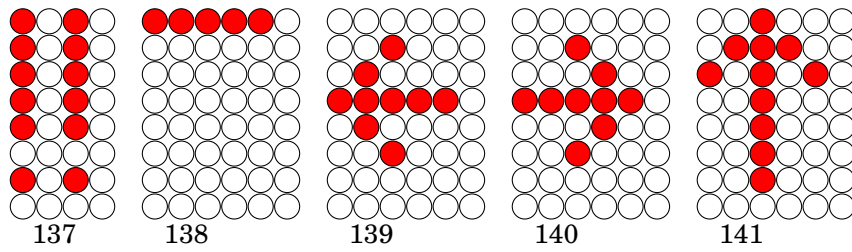
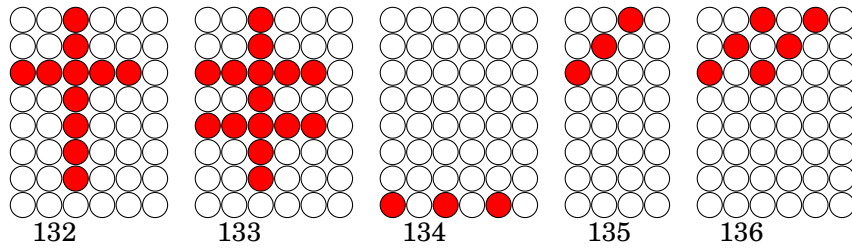
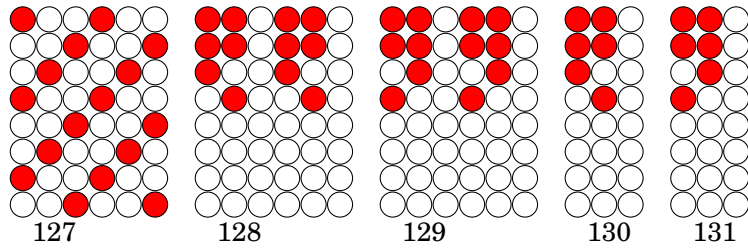
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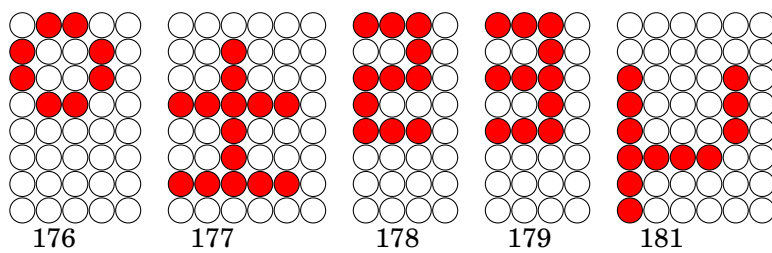
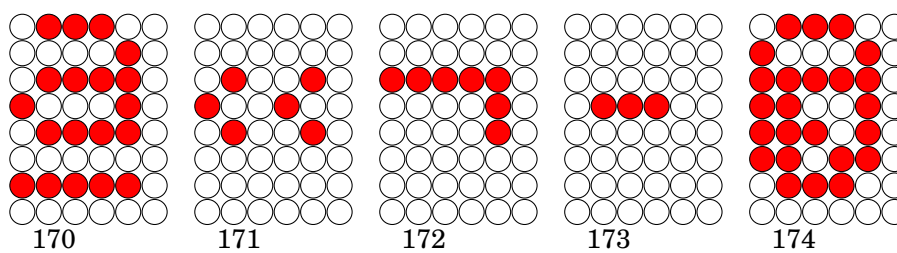
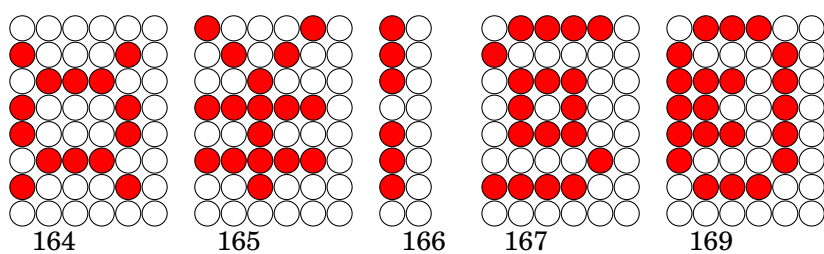
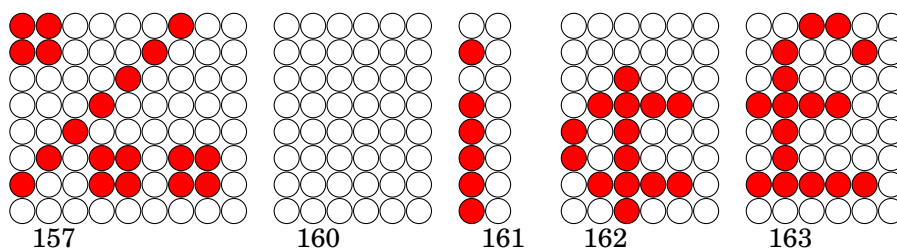
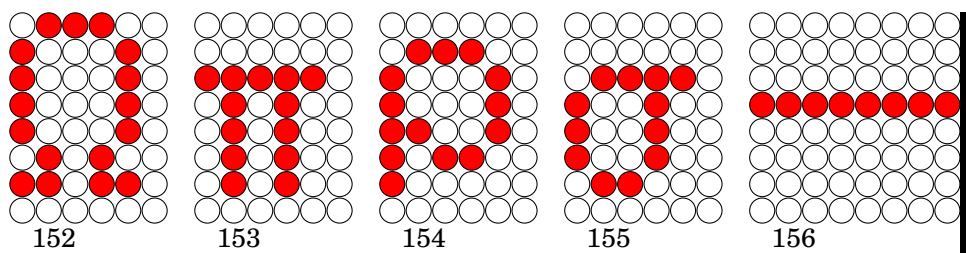


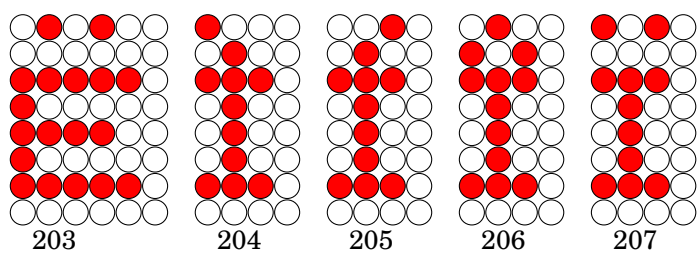
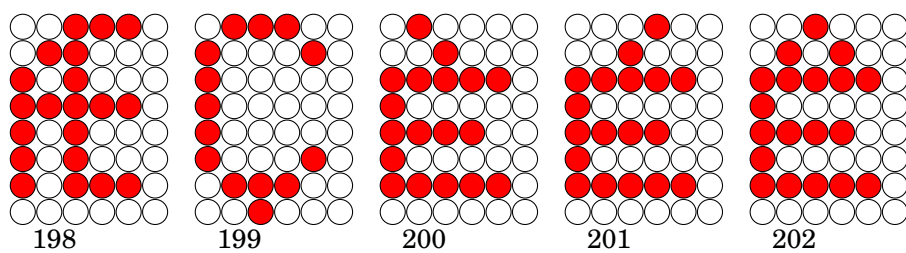
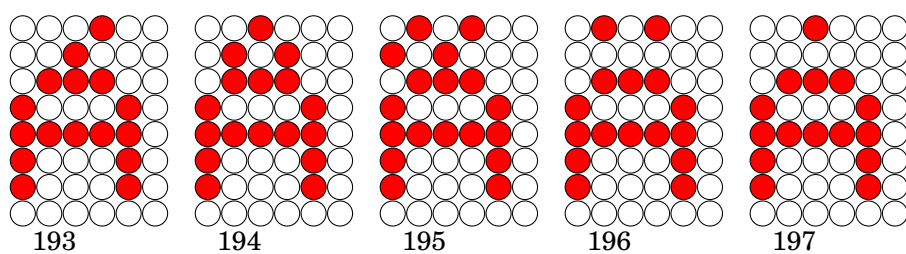
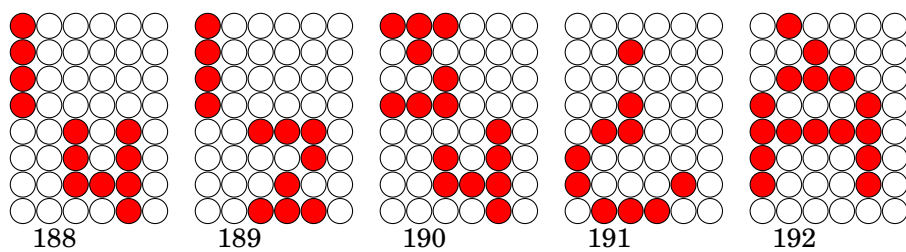
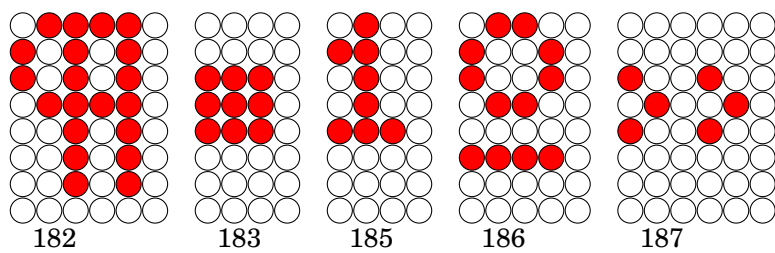




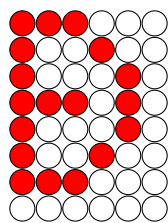




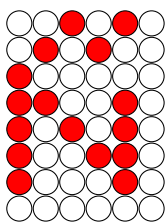




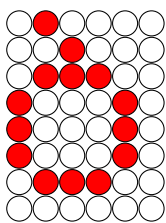




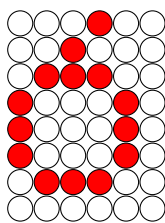
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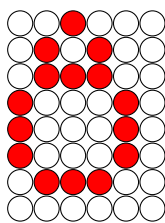
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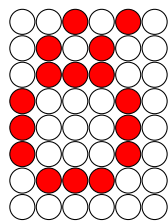
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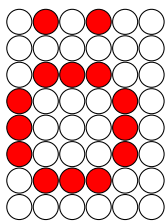
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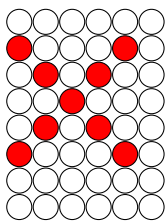
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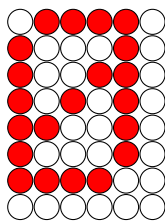
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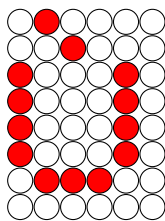
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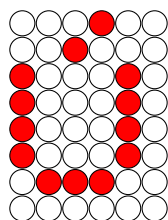
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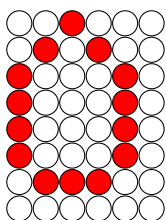
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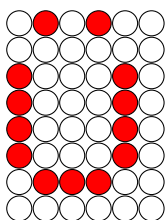
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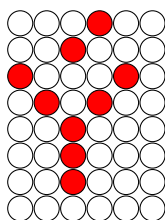
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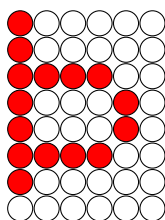
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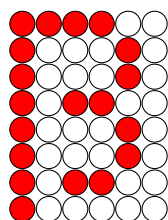
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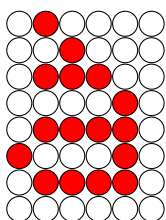
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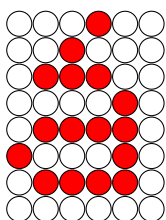
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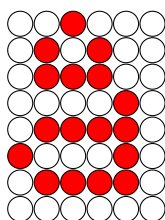
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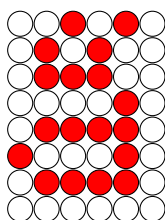
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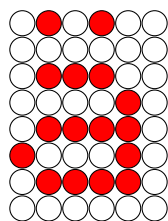
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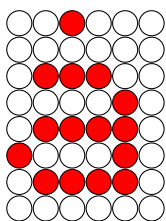
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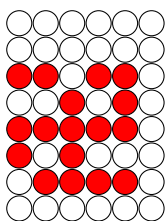
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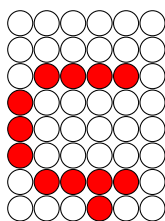
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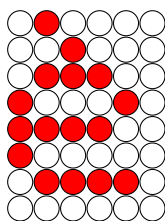
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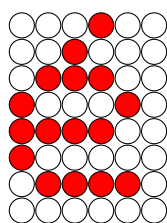
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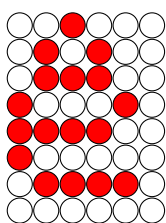
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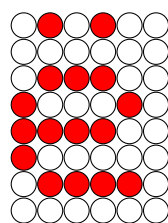
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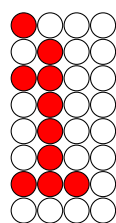
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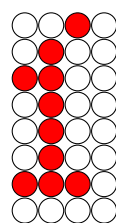
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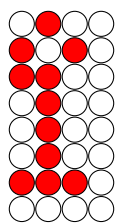
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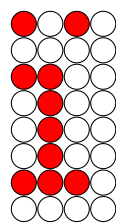
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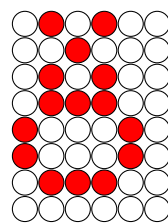
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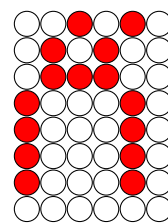
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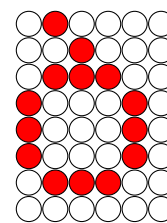
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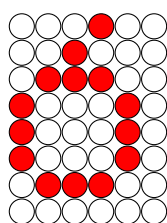
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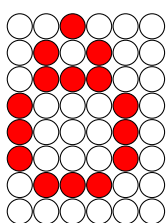
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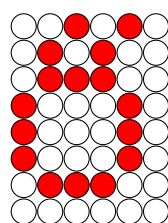
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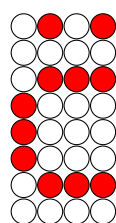
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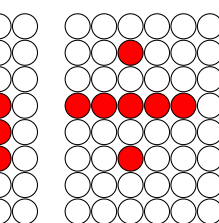
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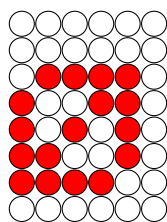
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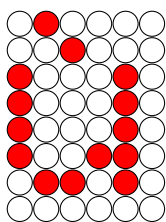
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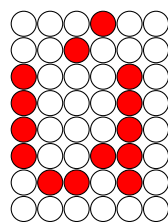
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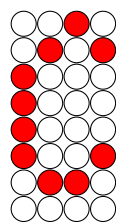
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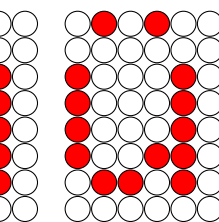
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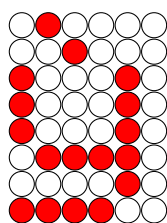
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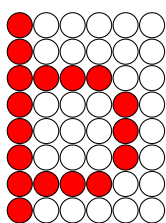
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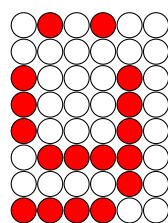
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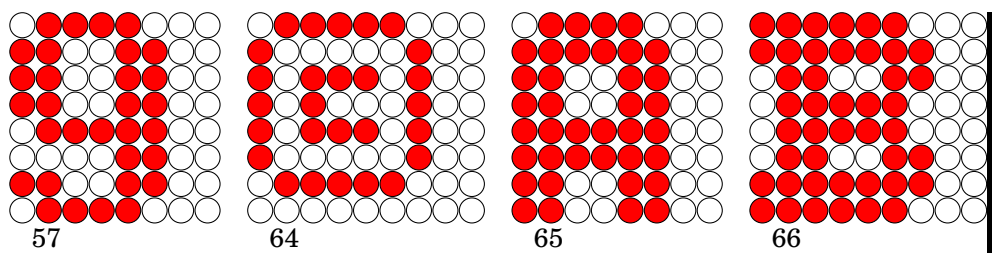
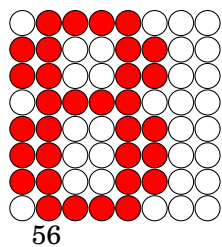
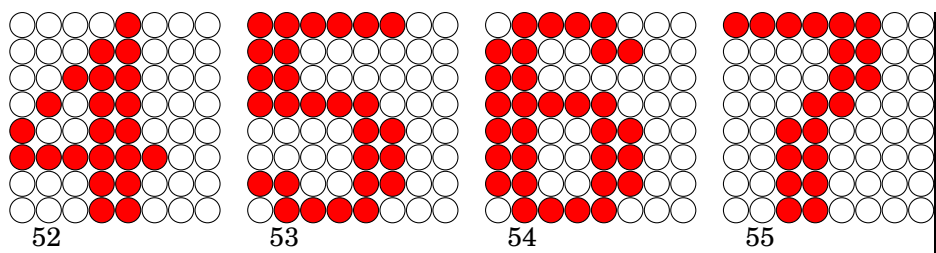
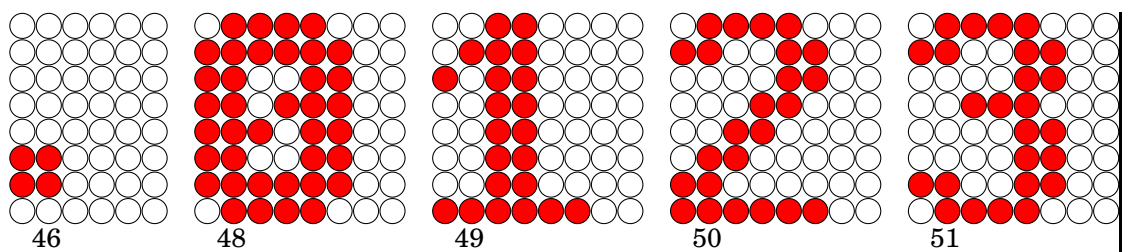
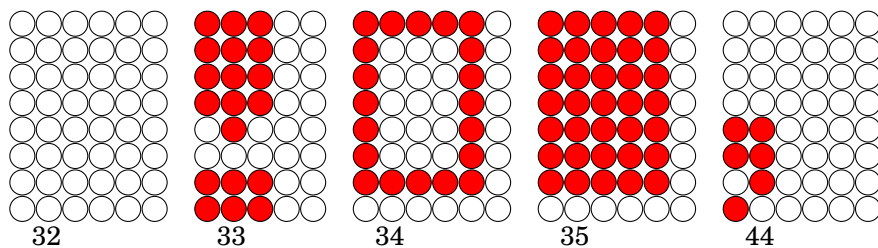


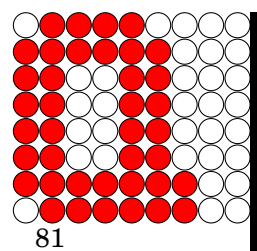
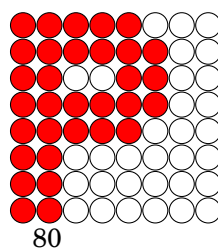
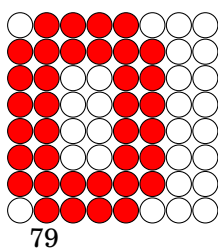
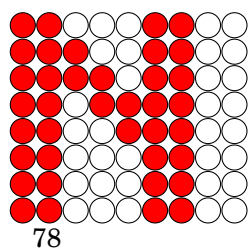
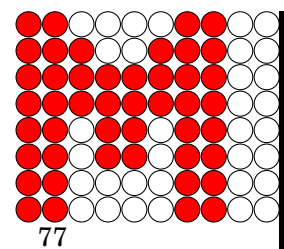
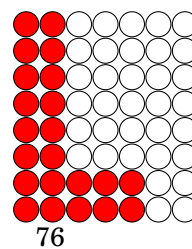
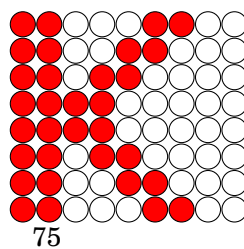
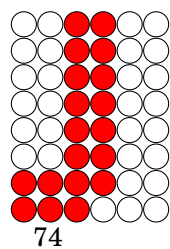
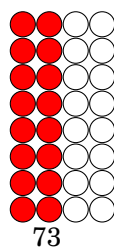
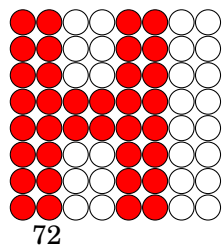
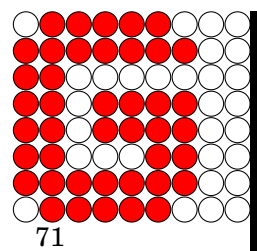
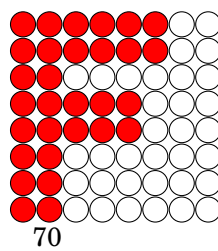
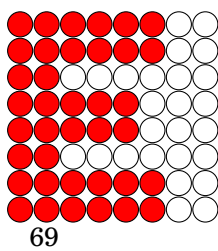
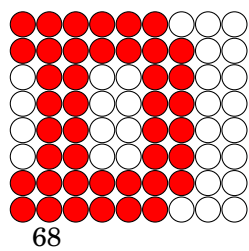
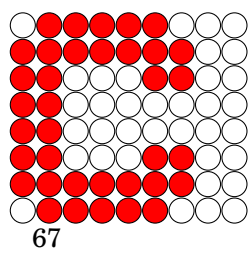
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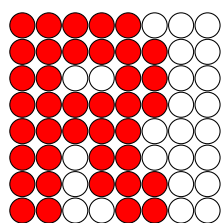


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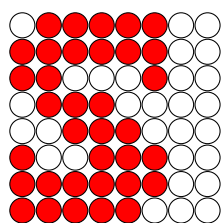


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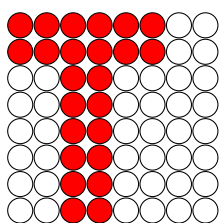




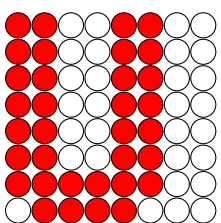
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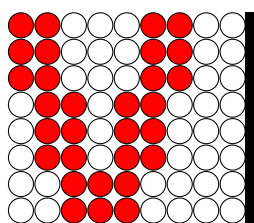
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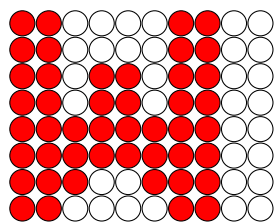
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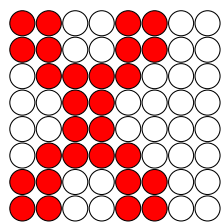
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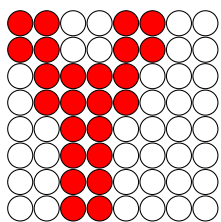
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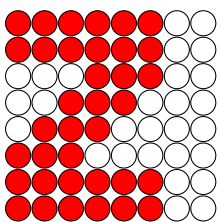
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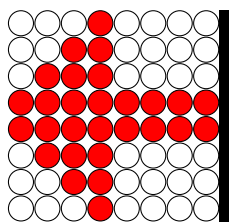
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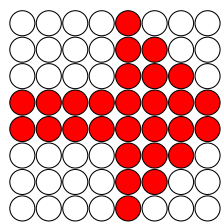
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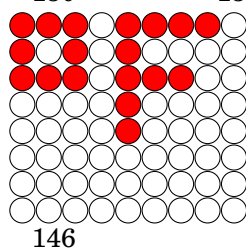
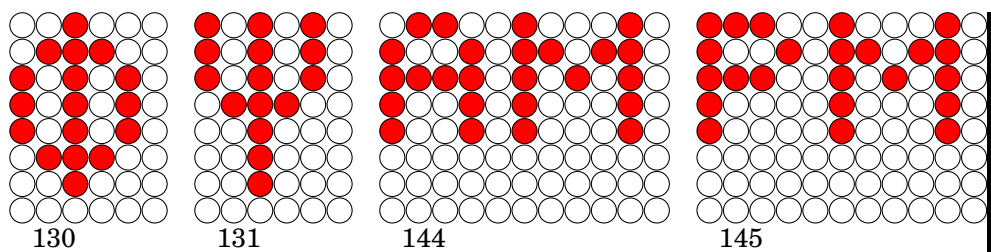
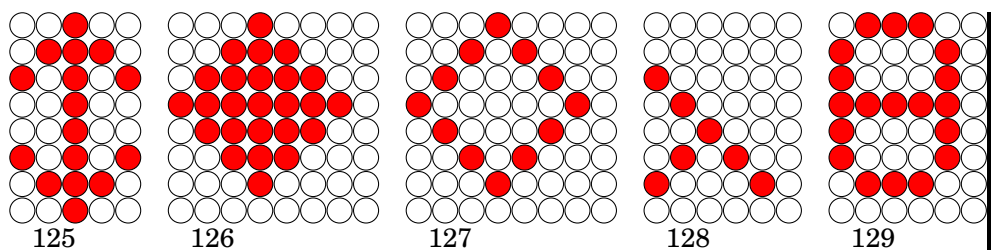
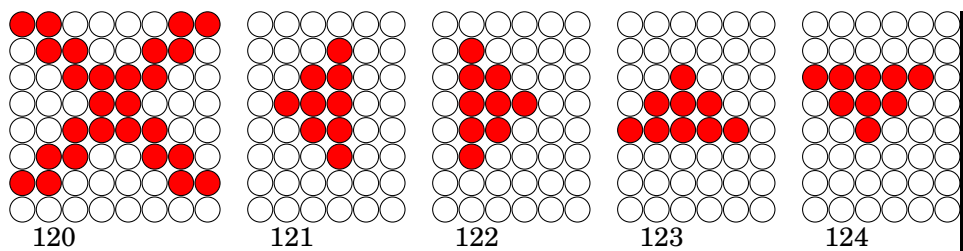
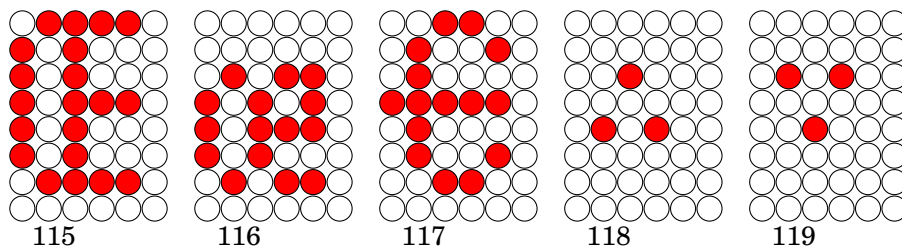
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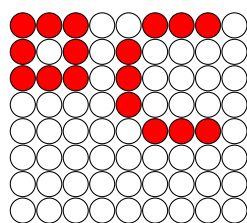


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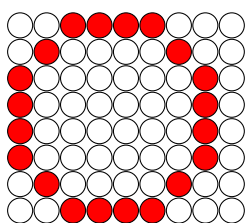


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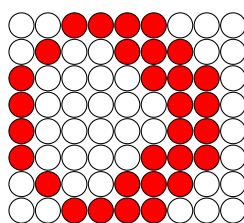




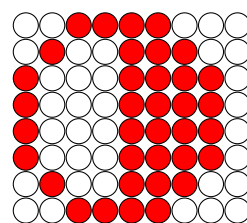
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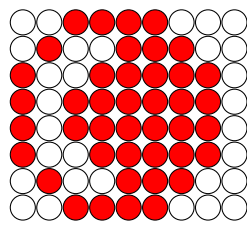
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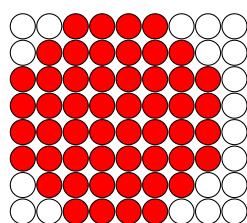
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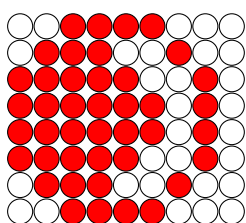
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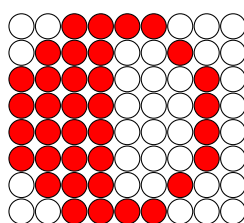
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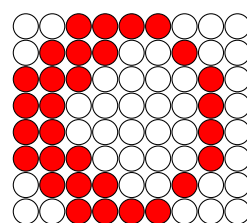
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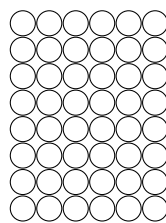
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158



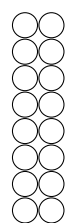
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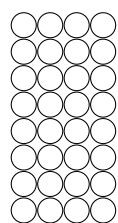
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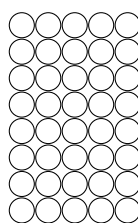
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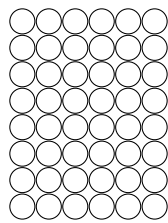
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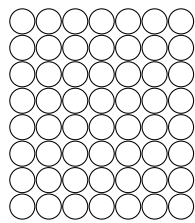
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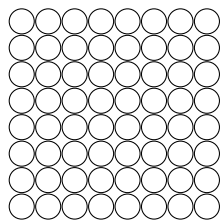
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# CHAPTER 6

## FUTURE IDEAS

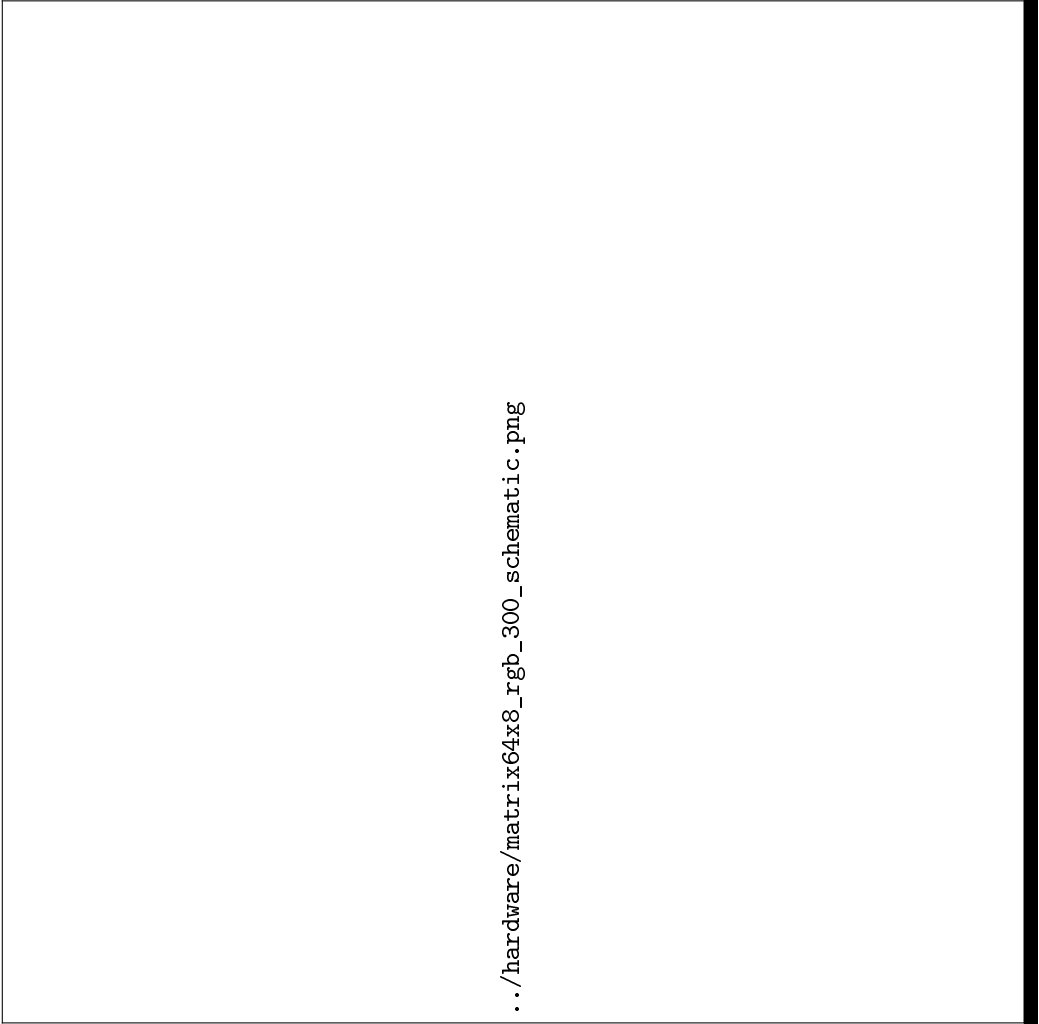
Encode a “flashing” attribute into matrix content, perhaps as a bit that is set on the color code, to allow arbitrary parts of the matrix to flash.



# CHAPTER 7

## SCHEMATICS AND DIAGRAMS

The following page includes the schematics for the current 3.2.1 version of the readerboard PCB and the board assembly diagram, showing where the components are placed.



../hardware/matrix64x8\_rgb\_300\_schematic.png

../hardware/matrix64x8\_rgb\_300\_assembly.png