FiveThirtyEight's Riddler Express

> Dakota Jones is back in action. In her quest to locate the Temple of Diametra, she has found another highly symmetric crystal. However, nefarious agents have again gotten wind of her plans, and now Dakota and the crystal are nowhere to be found.
>
> And so, you must once again recreate the crystal using the data from Dakota's laser scanner. As a reminder, the scanner takes a 3D object and records 2D cross-sectional slices along the third dimension. Here's the looping animation file the scanner produced for the crystal this time:
>
> What sort of three-dimensional shape is the crystal? No pressure — Dakota Jones, nay, the entire world, is counting on you to locate the lost temple!

Plan

My plan is to read in the slices of the GIF, extract the information as a binary mask, identify the corners of the maks, and plot these corners in 3D-space.

Setup

```
knitr::opts_chunk$set(echo = TRUE, comment = "#>")
library(plotly)
library(htmlwidgets)
library(tidyverse)
theme_set(theme_minimal())
```

Preparing the image data

I read in the GIF image data using the `read.gif()` function from the 'caTools' package.

```
gif_path <- file.path("assets", "crystal_538.gif")
gif <- caTools::read.gif(gif_path)
```

```
#> Warning in caTools::read.gif(gif_path): write.gif: file
'assets/crystal_538.gif'
#> contains multiple color-maps. Use 'frame' > 0.
```

The image is contained as a 3D matrix in the `image` slot. The image matrix is numeric where each number corresponds to a color in the slice.

```
names(gif)
```

```
#> [1] "image" "col" "transparent" "comment"
```

```
dim(gif$image)
```

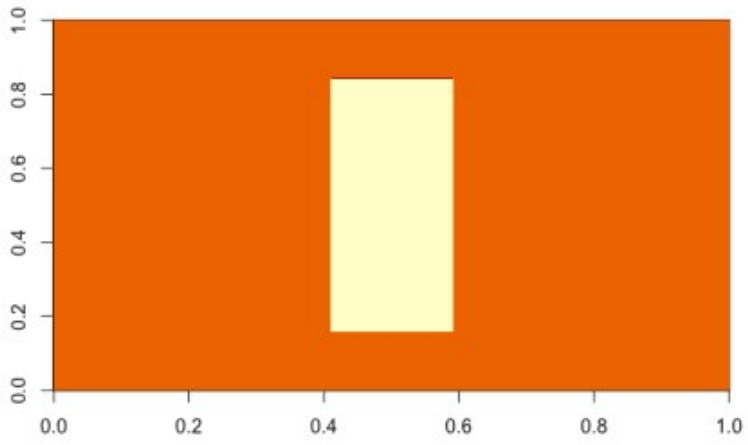
```
#> [1] 558 586 101
```

```
gif$image[1:5, 1:5, 1:3]
```

```
#> , , 1
#>
#> [,1] [,2] [,3] [,4] [,5]
#> [1,] 0 0 0 0 0
#> [2,] 0 0 0 0 0
#> [3,] 0 0 0 0 0
#> [4,] 0 0 0 0 0
#> [5,] 0 0 0 0 0
#>
#> , , 2
#>
#> [,1] [,2] [,3] [,4] [,5]
#> [1,] 2 2 2 2 2
#> [2,] 2 2 2 2 2
#> [3,] 2 2 2 2 2
#> [4,] 2 2 2 2 2
#> [5,] 2 2 2 2 2
#>
#> , , 3
#>
#> [,1] [,2] [,3] [,4] [,5]
#> [1,] 1 1 1 1 1
#> [2,] 1 1 1 1 1
#> [3,] 1 1 1 1 1
#> [4,] 1 1 1 1 1
#> [5,] 1 1 1 1 1
```

The built-in `image()` function can plot a matrix of numeric values.

```
image(gif$image[, , 21])
```



I expected to only find two colors, the foreground and background, but the edge of the foreground and background sometimes had a slightly different color.

```
table(gif$image[, , 20])
```

```
#>
#> 0 1 2
#> 38164 288012 812
```

```
table(gif$image[, , 21])
```

```
#>
#> 0 1 2 3
#> 40000 802 285986 200
```

```
table(gif$image[, , 22])
```

```
#>
#> 0 1 2
#> 41184 285012 792
```

Luckly, the foreground always had the color `0`. Therefore, I made a copy of the `gif$image` where all the 0 values were `TRUE` and the rest were `FALSE`.

```
img <- gif$image
img <- img == 0
```

Finally, the first and last frames are empty, so I removed them.

```
img <- img[, , -c(1, 101)]
```

‘Tidy’ the image data

I wanted to put the image data into a tidy format so that each row was a data point with columns `x`, `y`, and `z` (the slice of the GIF) for the data point’s coordinates and a column `value` for the value (either `TRUE` or `FALSE`) of the point. This was done by the `get_tidy_xy()` funciton that takes an index for which to slice `img`.

Then, I needed to get just the corners of the mask. Thankfully, this was easy because all of the individual shages were rectangles. Therefore, I

could just filter for the points at the minimum and maximum `x` values and then the minimum and maximum `y` values. This was done by `get_mask_corners()` that takes a tidy data frame like that produced by `get_tidy_xy()`.

Both of these functions were used in tandem to produce the `tidy_img` tibble.

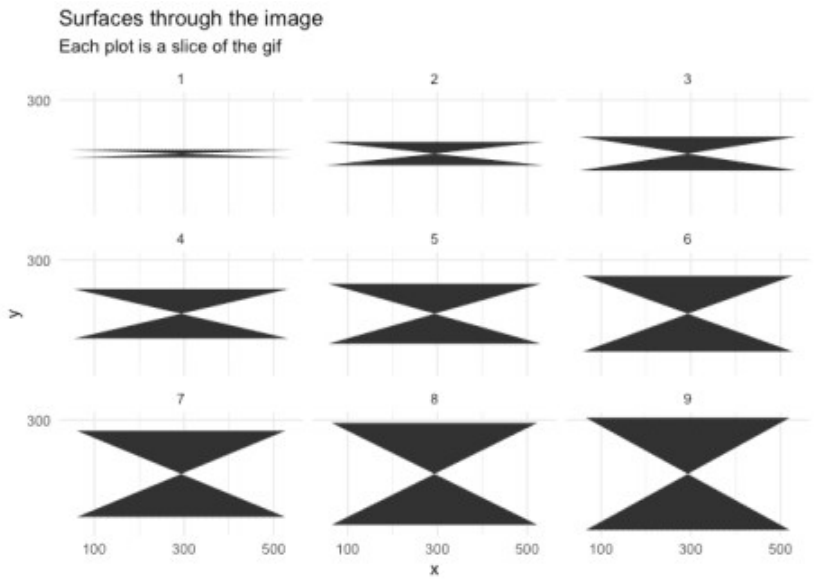
```
get_tidy_xy <- function(i) {
m <- img[, , i]
colnames(m) <- as.character(seq(1, ncol(m)))
as.data.frame(m) %>%
as_tibble() %>%
mutate(y = 1:n()) %>%
pivot_longer(-y, names_to = "x", values_to = "value") %>%
mutate(x = as.numeric(x))
}
get_mask_corners <- function(df) {
df %>%
filter(value) %>%
filter(x == min(x) | x == max(x)) %>%
filter(y == min(y) | y == max(y))
}
tidy_img <- tibble(z = seq(1, dim(img)[3])) %>%
mutate(xy = map(z, get_tidy_xy),
xy = map(xy, get_mask_corners)) %>%
unnest(xy)
tidy_img
```

```
#> # A tibble: 396 x 4
#> z y x value
#>
#> 1 1 278 46 TRUE
#> 2 1 278 541 TRUE
#> 3 1 281 46 TRUE
#> 4 1 281 541 TRUE
#> 5 2 275 49 TRUE
#> 6 2 275 538 TRUE
#> 7 2 284 49 TRUE
#> 8 2 284 538 TRUE
#> 9 3 273 51 TRUE
#> 10 3 273 536 TRUE
#> # … with 386 more rows
```

I used the 'ggforce' library to plot the first few layers, individually, before going to 3D.

```
tidy_img %>%
filter(z %in% 1:9) %>%
ggplot(aes(x = x, y = y, group = z)) +
facet_wrap(~ z) +
ggforce::geom_shape() +
scale_x_continuous(breaks = c(100, 300, 500)) +
scale_y_continuous(breaks = c(100, 300, 500)) +
theme(
panel.grid = element_line()
) +
labs(x = "x", y = "y",
title = "Surfaces through the image",
```

```
subtitle = "Each plot is a slice of the gif")
```



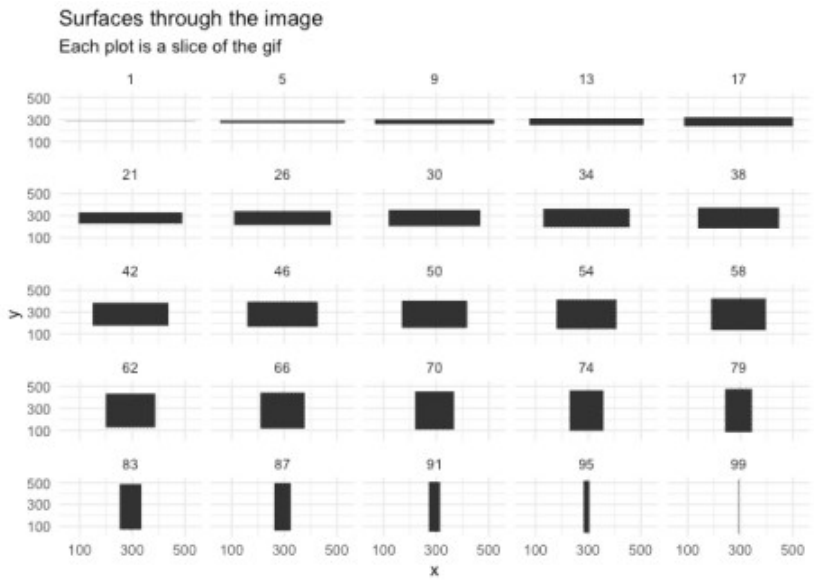
Instead of nice rectangles, this produced a bow-tie shape. This was because of the order of the points – they weree not in the correct order to draw a rectangle, but instead the top-left point was followed by the bottom-right point, causing the diagonal. Therefore, the `arrange_tidy_xy()` function just rearranges each coordinate to properly draw a rectangle.

```
arrange_tidy_xy <- function(df) {
df <- df[c(1, 2, 4, 3), ]
}
tidy_img <- tidy_img %>%
group_by(z) %>%
nest() %>%
mutate(data = map(data, arrange_tidy_xy)) %>%
unnest(data)
tidy_img
```

```
#> # A tibble: 396 x 4
#> # Groups: z [99]
#> z y x value
#>
#> 1 1 278 46 TRUE
#> 2 1 278 541 TRUE
#> 3 1 281 541 TRUE
#> 4 1 281 46 TRUE
#> 5 2 275 49 TRUE
#> 6 2 275 538 TRUE
#> 7 2 284 538 TRUE
#> 8 2 284 49 TRUE
#> 9 3 273 51 TRUE
#> 10 3 273 536 TRUE
#> # … with 386 more rows
```

```
tidy_img %>%
filter(z %in% round(seq(1, 99, length.out = 25))) %>%
ggplot(aes(x = x, y = y, group = z)) +
facet_wrap(~ z) +
ggforce::geom_shape() +
scale_x_continuous(breaks = c(100, 300, 500)) +
```

```
scale_y_continuous(breaks = c(100, 300, 500)) +
theme(
panel.grid = element_line()
) +
labs(x = "x", y = "y",
title = "Surfaces through the image",
subtitle = "Each plot is a slice of the gif")
```



3D Plotting

Finally, I could plot the points in 3D to create the shape of “Dakota Jones’ crystal” as the Riddle requests.

```
plot_ly(data = tidy_img, x = ~x, y = ~y, z = ~z, size = 1,
mode = "markers", opacity = 1.0, type = "scatter3d")
```

```
plot_ly(data = tidy_img, x = ~x, y = ~y, z = ~z, size = 1,
mode = "line", opacity = 0.5, type = "scatter3d")
```

```
plot_ly(data = tidy_img, x = ~x, y = ~y, z = ~z, type = "mesh3d")…
```