Supplemental Material for An Exploration of Exploration: Measuring the ability of lexicase selection to find obscure pathways

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2021-06-16

Contents

Chapter 1

Introduction

This is the supplemental material associated with our 2021 GPTP contribution entitled, *An Exploration of Exploration: Measuring the ability of lexicase selection to find obscure pathways*. Preprint forthcoming.

1.1 About our supplemental material

This supplemental material is hosted on GitHub using GitHub pages. The source code and configuration files used to generate this supplemental material can be found in this GitHub repository. We compiled our data analyses and supplemental documentation into this nifty web-accessible book using bookdown.

Our supplemental material includes the following:

- TODO

1.2 Contributing authors

- Jose Guadalupe Hernandez
- Alexander Lalejini
- Charles Ofria

1.3 Research overview

Abstract:

TODO

Chapter 2

Data Availability

2.1 Source code

The source code for this work is available on GitHub at https://github.com/jgh9094/GPTP-2021-Exploration-Of-Exploration.

2.2 Experimental results

The data from our experiments are available online in an OSF repository (Lalejini and Hernandez, 2021) at https://osf.io/xpjft/.

Chapter 3

Compile and run experiments

Here, we provide a guide to compiling and running our experiments using our Docker image.

Please file an issue on GitHub if something is unclear or does not work.

3.1 Docker

TODO

3.1.1 Getting the right image

3.1.1.1 DockerHub

3.1.1.2 Local build

3.1.2 Spinning up a container

3.1.3 Running inside the container

3.1.4 Copying content from the container

Chapter 4

Tournament selection vs Lexicase selection

4.1 Overview

```
# Relative location of data.
working_directory <- "experiments/2021-05-27-tournament/analysis/"
# working_directory <- "./"

# Settings for visualization
cb_palette <- "Set2"
# Create directory to dump plots
dir.create(paste0(working_directory, "imgs"), showWarnings=FALSE)
```

4.2 Analysis dependencies

```
library(ggplot2)
library(tidyverse)
library(cowplot)
library(viridis)
library(RColorBrewer)
source("https://gist.githubusercontent.com/benmarwick/2a1bb0133ff568cbe28d/raw/fb53bd97121f7f9ce9
```

These analyses were conducted in the following computing environment:

```
print(version)
```

```
##                _
## platform       x86_64-pc-linux-gnu
```

```
## arch           x86_64
## os             linux-gnu
## system         x86_64, linux-gnu
## status
## major          4
## minor          1.0
## year           2021
## month          05
## day            18
## svn rev        80317
## language       R
## version.string R version 4.1.0 (2021-05-18)
## nickname       Camp Pontanezen
```

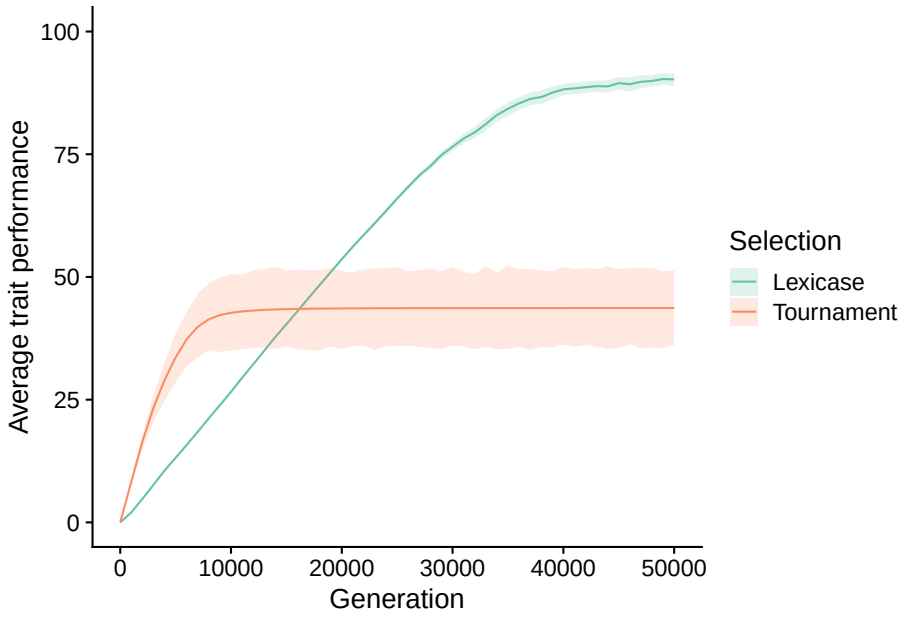
4.3 Setup

```
data_loc <- paste0(
  working_directory,
  "data/timeseries-res-1000g.csv"
)

data <- read.csv(data_loc, na.strings="NONE")

data$selection_name <- as.factor(
  data$selection_name
)

data$elite_trait_avg <-
  data$ele_agg_per / data$OBJECTIVE_CNT
data$unique_start_positions_coverage <-
  data$uni_str_pos / data$OBJECTIVE_CNT

final_data <- filter(data, evaluations==max(data$evaluations))

####### misc #######
# Configure our default graphing theme
theme_set(theme_cowplot())
```

4.4 Exploration diagnostic performance

```
elite_ave_performance_fig <- ggplot(
    data,
    aes(
```

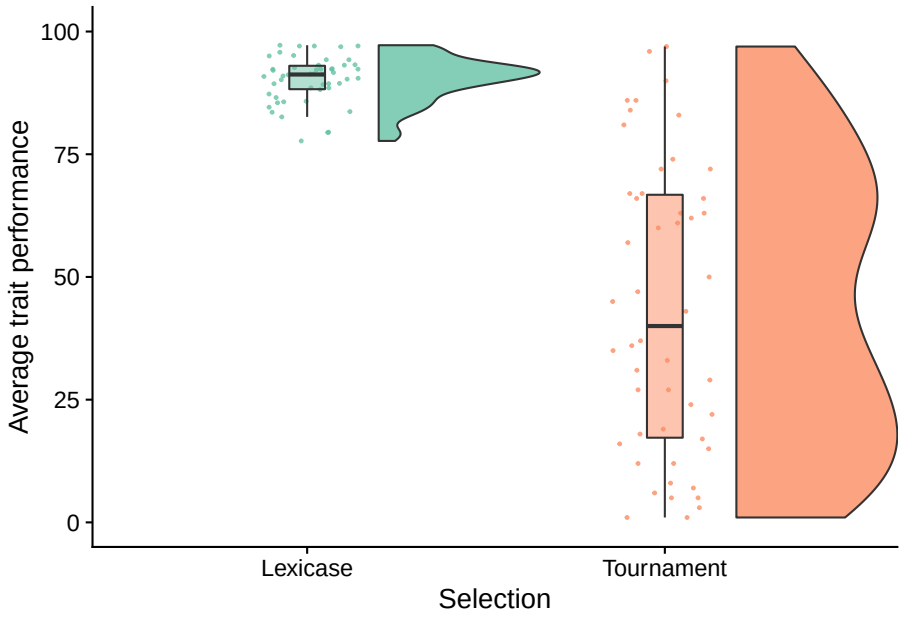
```
      x=gen,
      y=elite_trait_avg,
      color=selection_name,
      fill=selection_name
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Average trait performance",
    limits=c(0, 100)
  ) +
  scale_x_continuous(
    name="Generation"
  ) +
  scale_fill_brewer(
    name="Selection",
    limits=c("EpsilonLexicase", "Tournament"),
    labels=c("Lexicase", "Tournament"),
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Selection",
    limits=c("EpsilonLexicase", "Tournament"),
    labels=c("Lexicase", "Tournament"),
    palette=cb_palette
  )
elite_ave_performance_fig
```



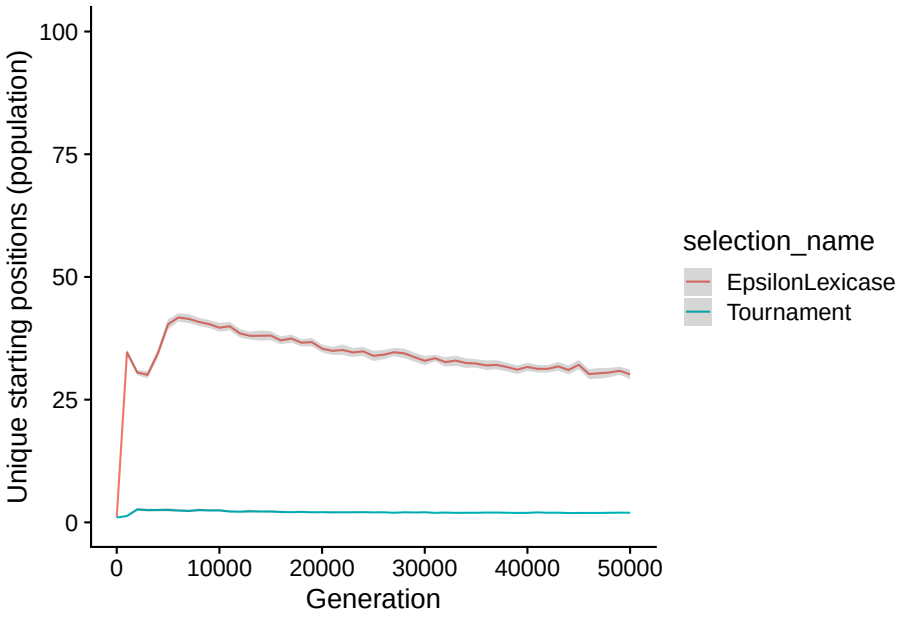
4.5 Final Performance

```
elite_final_performance_fig <- ggplot(
    final_data,
    aes(
      x=selection_name,
      y=elite_trait_avg,
      fill=selection_name
    )
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=selection_name),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
```

```
    outlier.shape = NA,
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Average trait performance",
    limits=c(0, 100)
  ) +
  scale_x_discrete(
    name="Selection",
    limits=c("EpsilonLexicase", "Tournament"),
    labels=c("Lexicase", "Tournament"),
  ) +
  scale_fill_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("EpsilonLexicase", "Tournament"),
    labels=c("Lexicase", "Tournament"),
  ) +
  scale_color_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("EpsilonLexicase", "Tournament"),
    labels=c("Lexicase", "Tournament"),
  ) +
  theme(
    legend.position="none"
  )
elite_final_performance_fig
```



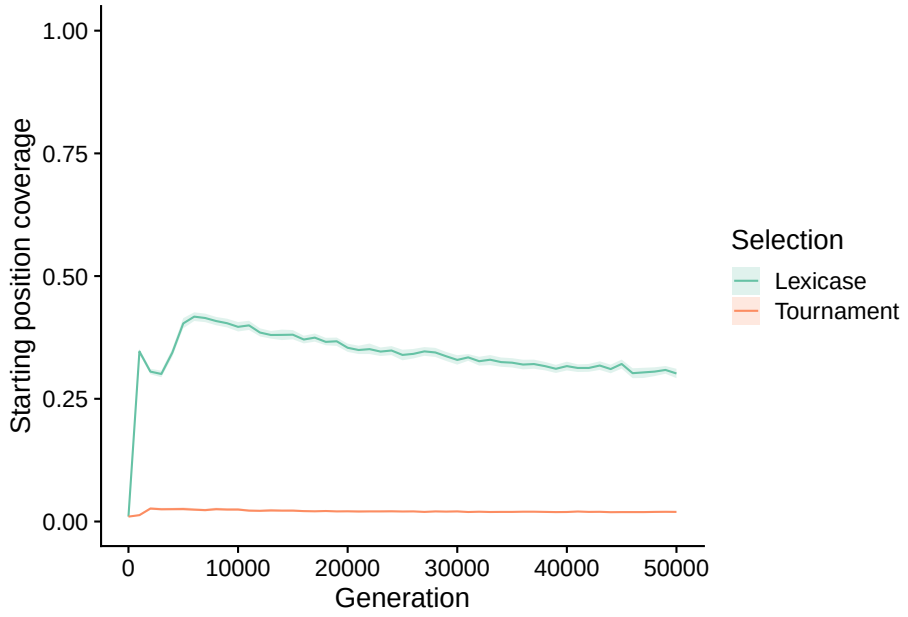

```
ggplot(data, aes(x=gen, y=uni_str_pos, color=selection_name)) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Unique starting positions (population)",
    limits=c(0, 100)
  ) +
  scale_x_continuous(
    name="Generation"
  )
```



Different cardinalities have numbers of possible starting positions, so next, we look at the proportion of starting positions (out of all possible) maintained by populations.

```
unique_start_position_coverage_fig <- ggplot(
    data,
    aes(
      x=gen,
      y=unique_start_positions_coverage,
      color=selection_name,
      fill=selection_name
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limit=c(0, 1.0)
  ) +
```

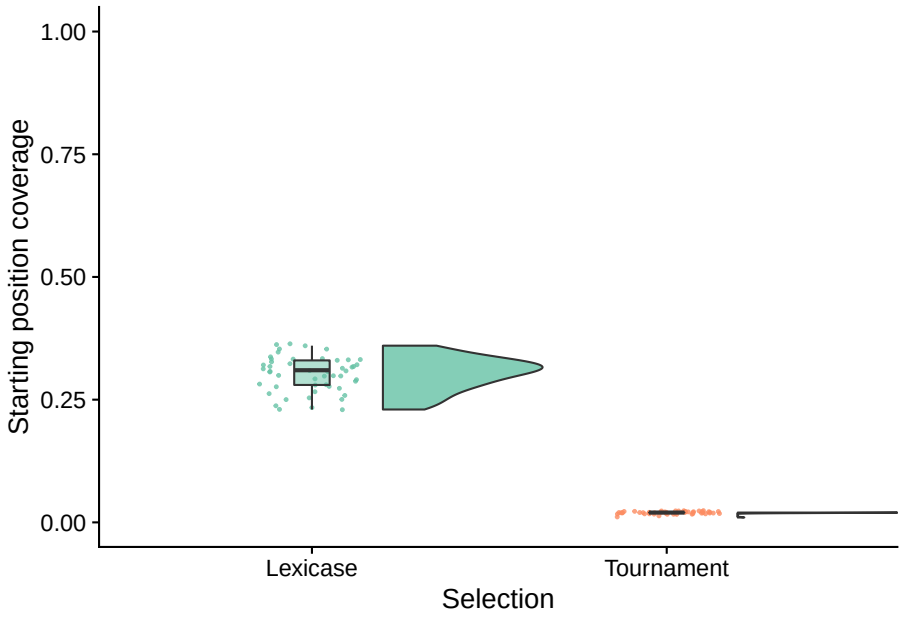
```
  scale_x_continuous(
    name="Generation"
  ) +
  scale_fill_brewer(
    name="Selection",
    limits=c("EpsilonLexicase", "Tournament"),
    labels=c("Lexicase", "Tournament"),
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Selection",
    limits=c("EpsilonLexicase", "Tournament"),
    labels=c("Lexicase", "Tournament"),
    palette=cb_palette
  )
unique_start_position_coverage_fig
```



4.6.1 Final starting position Coverage

```
unique_start_positions_coverage_final_fig <- ggplot(
    final_data,
    aes(
      x=selection_name,
      y=unique_start_positions_coverage,
```

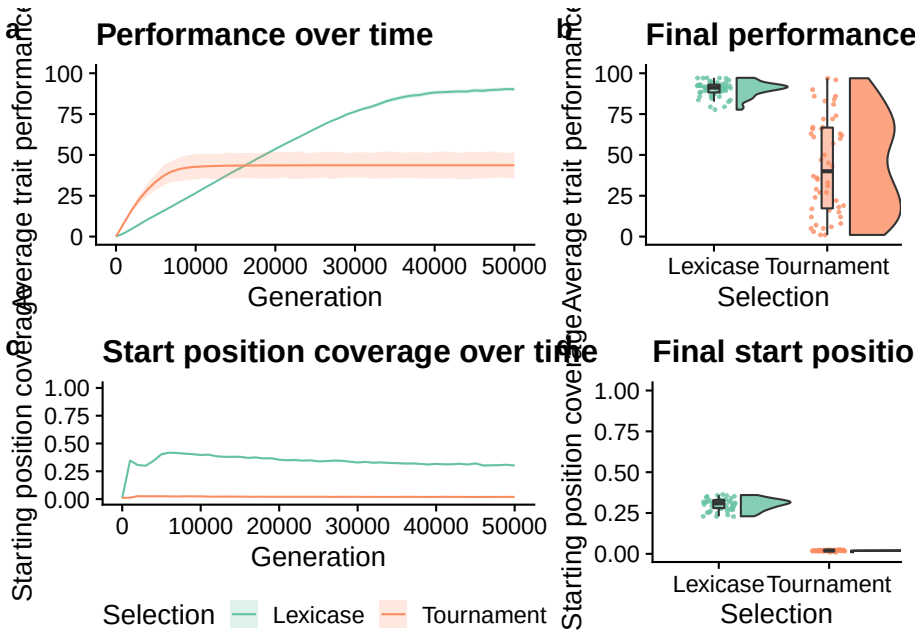
```
      fill=selection_name
    )
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=selection_name),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0, 1.0)
  ) +
  scale_x_discrete(
    name="Selection",
    limits=c("EpsilonLexicase", "Tournament"),
    labels=c("Lexicase", "Tournament"),
  ) +
  scale_fill_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("EpsilonLexicase", "Tournament"),
    labels=c("Lexicase", "Tournament"),
  ) +
  scale_color_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("EpsilonLexicase", "Tournament"),
    labels=c("Lexicase", "Tournament"),
  ) +
  theme(
    legend.position="none"
  )
unique_start_positions_coverage_final_fig
```



4.7 Manuscript figures

```
grid <- plot_grid(
  elite_ave_performance_fig +
    ggtitle("Performance over time") +
    theme(legend.position="none"),
  elite_final_performance_fig +
    ggtitle("Final performance") +
    theme(),
  unique_start_position_coverage_fig +
    ggtitle("Start position coverage over time") +
    guides(
      color = guide_legend(nrow = 1),
      fill=guide_legend(nrow = 1)
    ) +
    theme(
      legend.position="bottom",
      legend.box="horizontal"
    ),
  unique_start_positions_coverage_final_fig +
    ggtitle("Final start position coverage") +
    theme(),
  nrow=2,
```

```
  ncol=2,
  rel_widths=c(3,2),
  labels="auto"
)

save_plot(
  paste(
    working_directory,
    "imgs/tournament-vs-lexicase-panel.pdf",
    sep=""
  ),
  grid,
  base_width=12,
  base_height=8
)

grid
```



Chapter 5

Diagnostic cardinality

5.1 Overview

```
# Relative location of data.
working_directory <-
  "experiments/2021-05-27-cardinality/analysis/"
# working_directory <- "./"

# Settings for visualization
cb_palette <- "Set2"
# Create directory to dump plots
dir.create(paste0(working_directory, "imgs"), showWarnings=FALSE)
```

5.2 Analysis dependencies

```
library(ggplot2)
library(tidyverse)
library(cowplot)
library(viridis)
library(RColorBrewer)
source("https://gist.githubusercontent.com/benmarwick/2a1bb0133ff568cbe28d/raw/fb53bd97121f7f9ce9
```

These analyses were conducted in the following computing environment:

```
print(version)
```

```
##                _
## platform       x86_64-pc-linux-gnu
## arch           x86_64
```

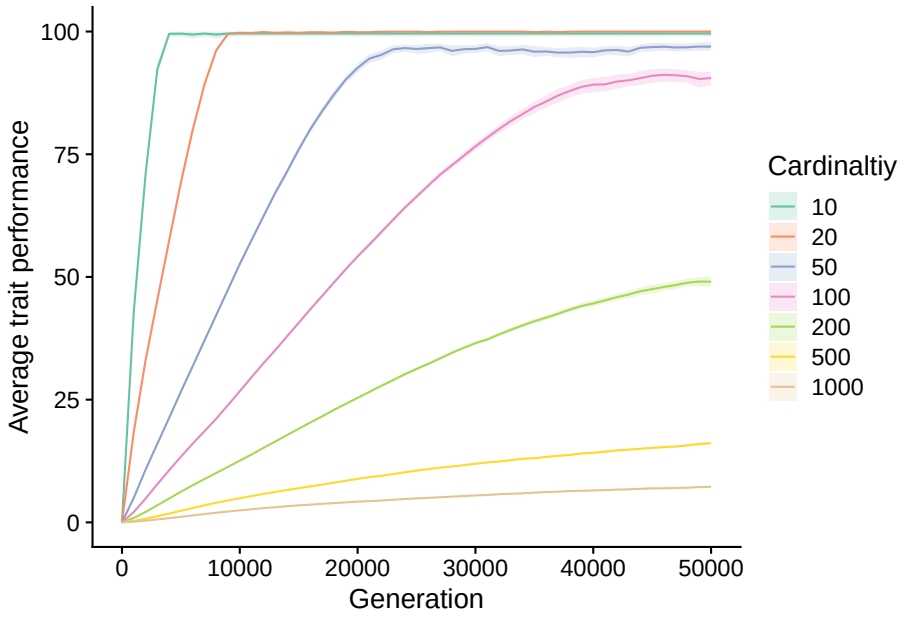
```
## os             linux-gnu
## system         x86_64, linux-gnu
## status
## major          4
## minor          1.0
## year           2021
## month          05
## day            18
## svn rev        80317
## language       R
## version.string R version 4.1.0 (2021-05-18)
## nickname       Camp Pontanezen
```

```
data_loc <- paste0(
  working_directory,
  "data/timeseries-res-1000g.csv"
)
data <- read.csv(
  data_loc,
  na.strings="NONE"
)

data$cardinality <- as.factor(
  data$OBJECTIVE_CNT
)
data$selection_name <- as.factor(
  data$selection_name
)

data$elite_trait_avg <-
  data$ele_agg_per / data$OBJECTIVE_CNT

data$unique_start_positions_coverage <-
  data$uni_str_pos / data$OBJECTIVE_CNT

####### misc #######
# Configure our default graphing theme
theme_set(theme_cowplot())
```

5.4 Exploration diagnostic performance

First, we look at performance over time. Specifically, we look at the normalized aggregage score of the most performant individuals over time. To control for different cardinalities having different maximum scores, we normalized performances (by dividing by cardinality) to values between 0 and 100.

```
elite_trait_ave_fit <- ggplot(
    data,
    aes(
      x=gen,
      y=elite_trait_avg,
      color=cardinality,
      fill=cardinality
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Average trait performance",
    limits=c(0, 100)
  ) +
  scale_x_continuous(
    name="Generation"
  ) +
  scale_fill_brewer(
    name="Cardinaltiy",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Cardinaltiy",
    palette=cb_palette
  )
elite_trait_ave_fit
```

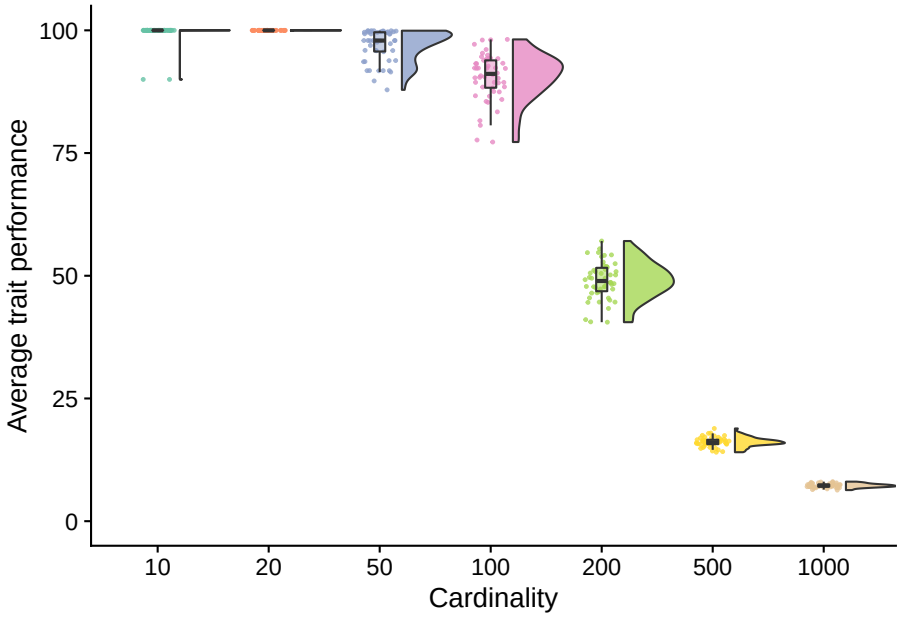


5.4.1 Final performance

Next, we look only at the final performances of each treatment

```
final_data <- filter(data, gen==max(data$gen))
elite_trait_ave_fit_final <- ggplot(
    final_data,
    aes(x=cardinality, y=elite_trait_avg, fill=cardinality)
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=cardinality),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
    alpha = 0.5
  ) +
```

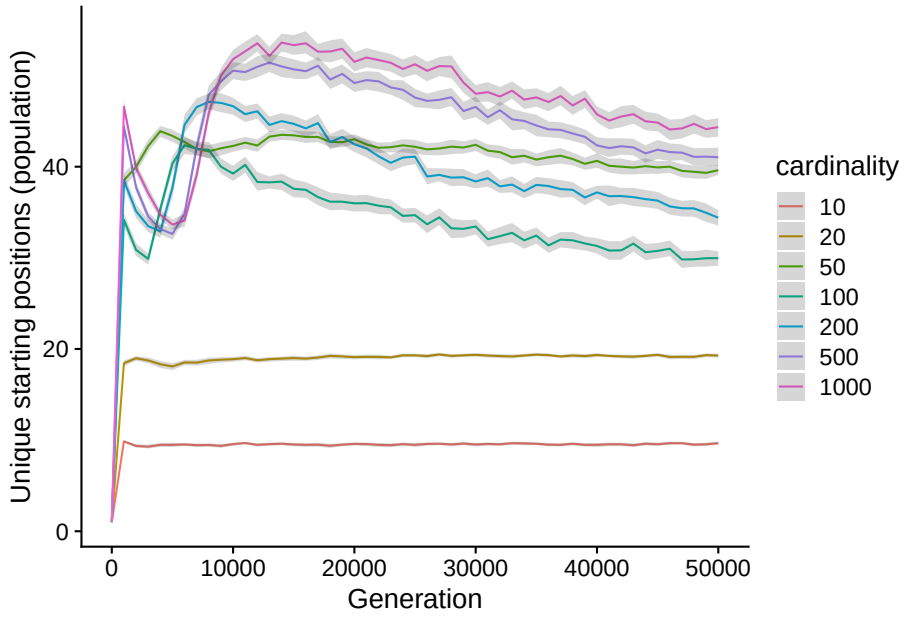
```
  scale_y_continuous(
    name="Average trait performance",
    limits=c(0, 100)
  ) +
  scale_x_discrete(
    name="Cardinality"
  ) +
  scale_fill_brewer(
    name="Cardinaltiy",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Cardinaltiy",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
elite_trait_ave_fit_final
```



5.5 Unique starting positions

Next, we analyze the number of unique starting position maintained by populations.

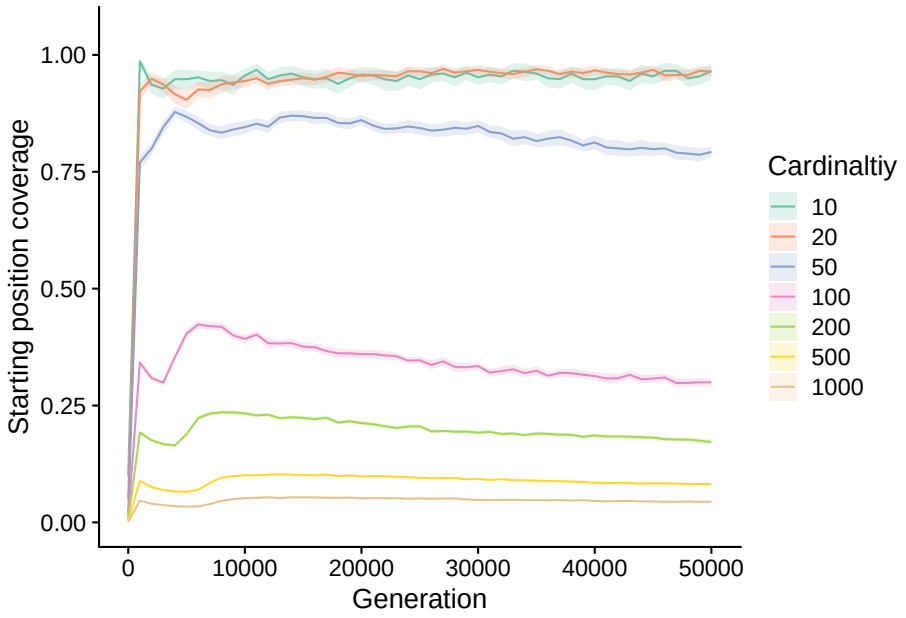
```
ggplot(data, aes(x=gen, y=uni_str_pos, color=cardinality)) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Unique starting positions (population)",
  ) +
  scale_x_continuous(
    name="Generation"
  )
```



Different cardinalities have numbers of possible starting positions, so next, we look at the proportion of starting positions (out of all possible) maintained by populations.

```
unique_start_positions_coverage_fig <- ggplot(
    data,
    aes(
      x=gen,
      y=unique_start_positions_coverage,
```

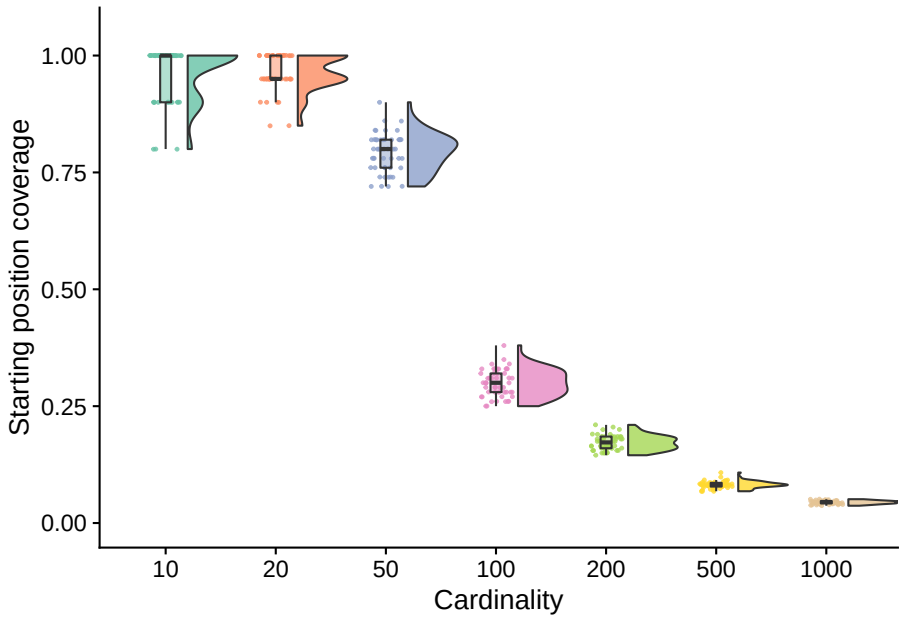
```
      color=cardinality,
      fill=cardinality
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0.0, 1.05)
  ) +
  scale_x_continuous(
    name="Generation"
  ) +
  scale_fill_brewer(
    name="Cardinaltiy",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Cardinaltiy",
    palette=cb_palette
  )
unique_start_positions_coverage_fig
```



5.5.1 Final starting position coverage

```
final_unique_start_positions_coverage_fig <- ggplot(
    final_data,
    aes(
      x=cardinality,
      y=unique_start_positions_coverage,
      fill=cardinality
    )
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=cardinality),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
```

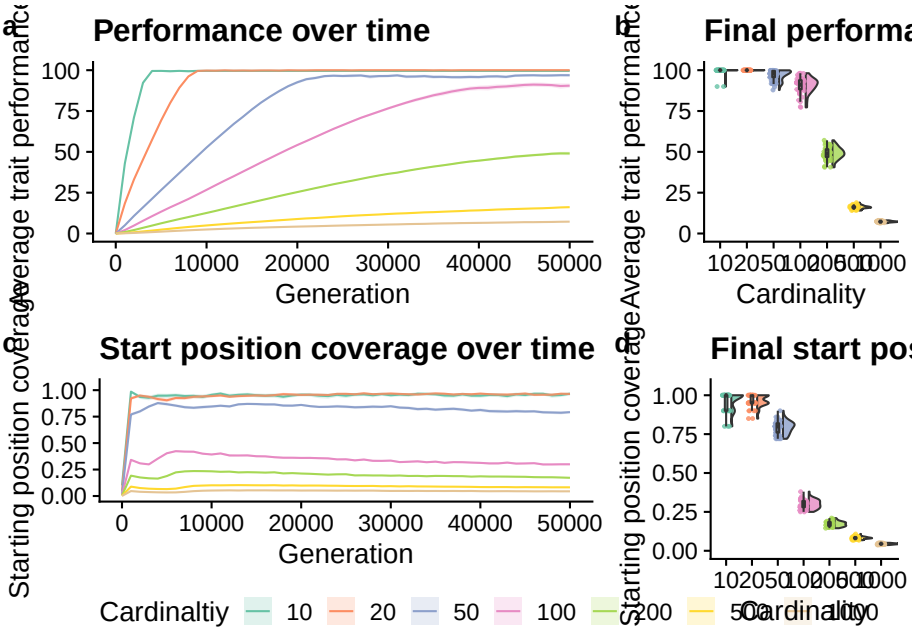
```
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0, 1.05)
  ) +
  scale_x_discrete(
    name="Cardinality"
  ) +
  scale_fill_brewer(
    name="Cardinaltiy",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Cardinaltiy",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
final_unique_start_positions_coverage_fig
```



5.6 Manuscript figures

Combine figures for the manuscript.

```
grid <- plot_grid(
  elite_trait_ave_fit +
    ggtitle("Performance over time") +
    theme(legend.position="none"),
  elite_trait_ave_fit_final +
    ggtitle("Final performance") +
    theme(),
  unique_start_positions_coverage_fig +
    ggtitle("Start position coverage over time") +
    guides(color=guide_legend(nrow = 1), fill=guide_legend(nrow=1)) +
    theme(
      legend.position="bottom",
      legend.box="horizontal"
    ),
  final_unique_start_positions_coverage_fig +
    ggtitle("Final start position coverage") +
    theme(),
  nrow=2,
  ncol=2,
  rel_widths=c(2,1),
  labels="auto"
)

save_plot(
  paste(working_directory, "imgs/cardinality-panel.pdf", sep=""),
  grid,
  base_width=12,
  base_height=10
)

grid
```


A
Performance over time
Average trait performance
100
75
50
25
0
0
10000
20000
30000
40000
50000
Generation
B
Final performa
Average trait performance
Cardinality
C
Start position coverage over time
Starting position coverage
1.00
0.75
0.50
0.25
0.00
Generation
D
Final start po
Starting position coverage
Cardinality
Cardinaltiy
10
20
50
100
200
500
1000

Chapter 6

Increasing population size versus increasing generations

6.1 Overview

```
# Relative location of data.
working_directory <-
  "experiments/2021-06-03-cardinality-pop-size/analysis/"
# working_directory <- "./"

# Settings for visualization
cb_palette <- "Set2"

# Create directory to dump plots
dir.create(paste0(working_directory, "imgs"), showWarnings=FALSE)
```

6.2 Analysis dependencies

```
library(ggplot2)
library(tidyverse)
library(cowplot)
library(viridis)
library(RColorBrewer)
source("https://gist.githubusercontent.com/benmarwick/2a1bb0133ff568cbe28d/raw/fb53bd97121f7f9ce9
```

These analyses were conducted in the following computing environment:

```
print(version)
```

```
##                _
## platform       x86_64-pc-linux-gnu
## arch           x86_64
## os             linux-gnu
## system         x86_64, linux-gnu
## status
## major          4
## minor          1.0
## year           2021
## month          05
## day            18
## svn rev        80317
## language       R
## version.string R version 4.1.0 (2021-05-18)
## nickname       Camp Pontanezen
```

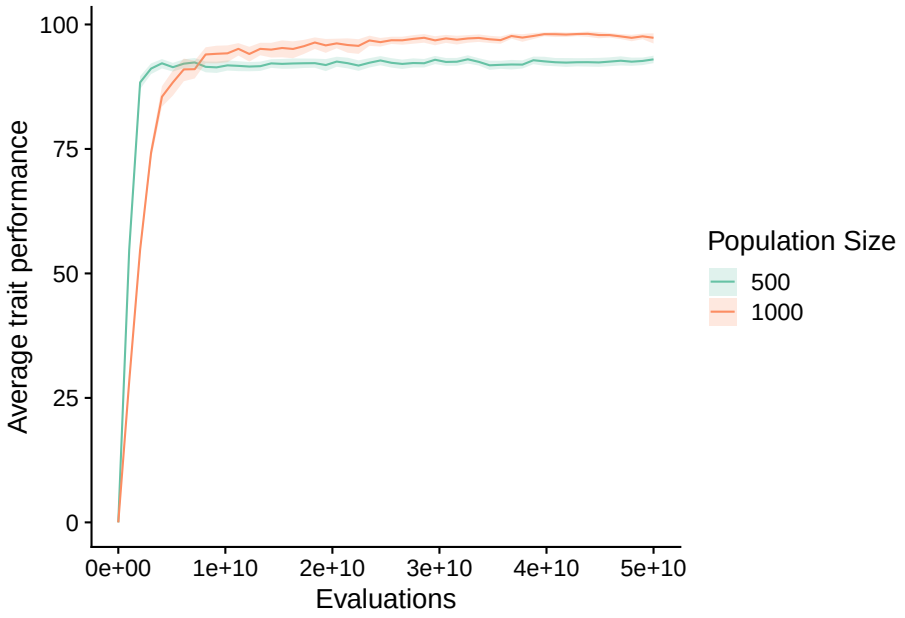
6.3 Setup

```
data_loc <- paste0(working_directory, "data/timeseries.csv")
data <- read.csv(data_loc, na.strings="NONE")

data$cardinality <- as.factor(
  data$OBJECTIVE_CNT
)
data$selection_name <- as.factor(
  data$selection_name
)

data$epsilon <- as.factor(
  data$LEX_EPS
)

data$POP_SIZE <- as.factor(
  data$POP_SIZE
)

data <- filter(data, cardinality=="100") # These runs finished.
data$elite_trait_avg <-
  data$ele_agg_per / data$OBJECTIVE_CNT
data$unique_start_positions_coverage <-
  data$uni_str_pos / data$OBJECTIVE_CNT
```

```
final_data <- filter(data, evaluations==max(data$evaluations))

####### misc #######
# Configure our default graphing theme
theme_set(theme_cowplot())
```

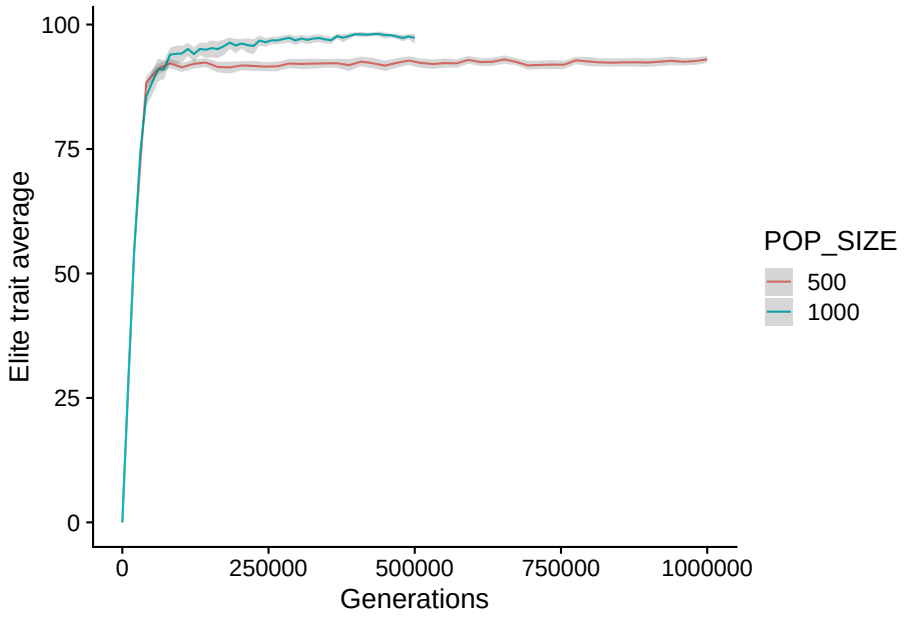
6.4 Exploration diagnostic performance

```
elite_ave_performance_fig <-
  ggplot(
    data,
    aes(
      x=evaluations,
      y=elite_trait_avg,
      color=POP_SIZE,
      fill=POP_SIZE
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Average trait performance"
  ) +
  scale_x_continuous(
    name="Evaluations"
  ) +
  scale_fill_brewer(
    name="Population Size",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Population Size",
    palette=cb_palette
  )
elite_ave_performance_fig
```



Same as above, but by generations instead of evaluations.

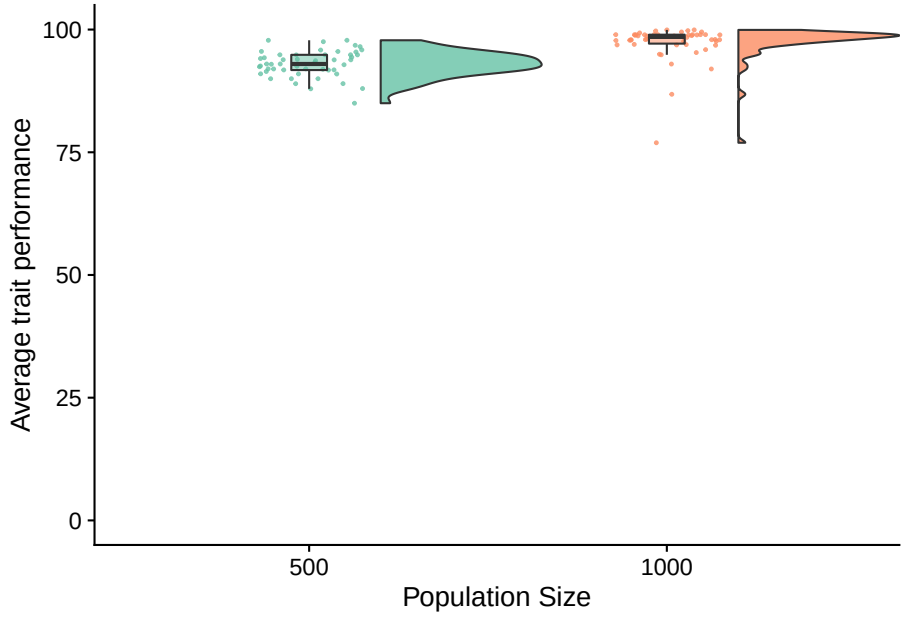
```
ggplot(data, aes(x=gen, y=elite_trait_avg, color=POP_SIZE)) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Elite trait average"
  ) +
  scale_x_continuous(
    name="Generations"
  )
```



6.4.1 Final performance

```
elite_final_performance_fig <- ggplot(
    final_data,
    aes(x=POP_SIZE, y=elite_trait_avg, fill=POP_SIZE)
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=POP_SIZE),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Average trait performance",
```

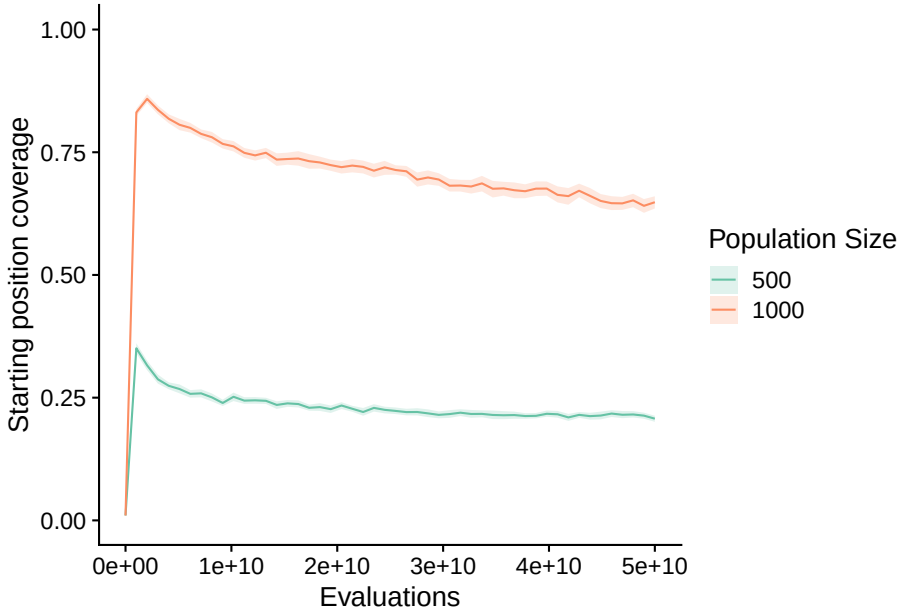
```
    limits=c(0, 100)
  ) +
  scale_x_discrete(
    name="Population Size"
  ) +
  scale_fill_brewer(
    name="Population Size",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Population Size",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
elite_final_performance_fig
```



6.5 Unique starting positions

```
unique_start_position_coverage_fig <- ggplot(
    data,
    aes(
```

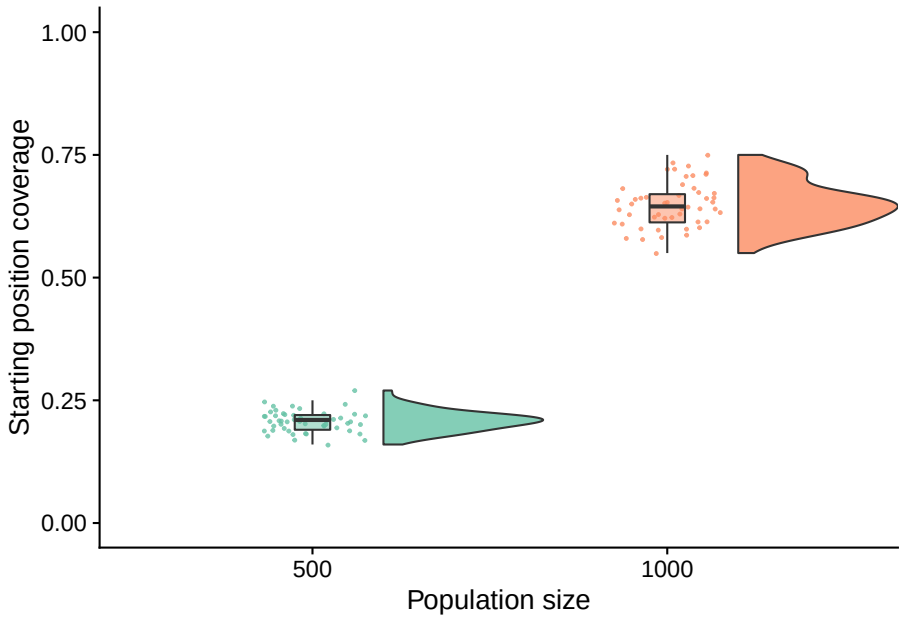
```
      x=evaluations,
      y=unique_start_positions_coverage,
      color=POP_SIZE,
      fill=POP_SIZE
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0.0, 1.0)
  ) +
  scale_x_continuous(
    name="Evaluations"
  ) +
  scale_fill_brewer(
    name="Population Size",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Population Size",
    palette=cb_palette
  )
unique_start_position_coverage_fig
```



6.5.1 Final starting position coverage

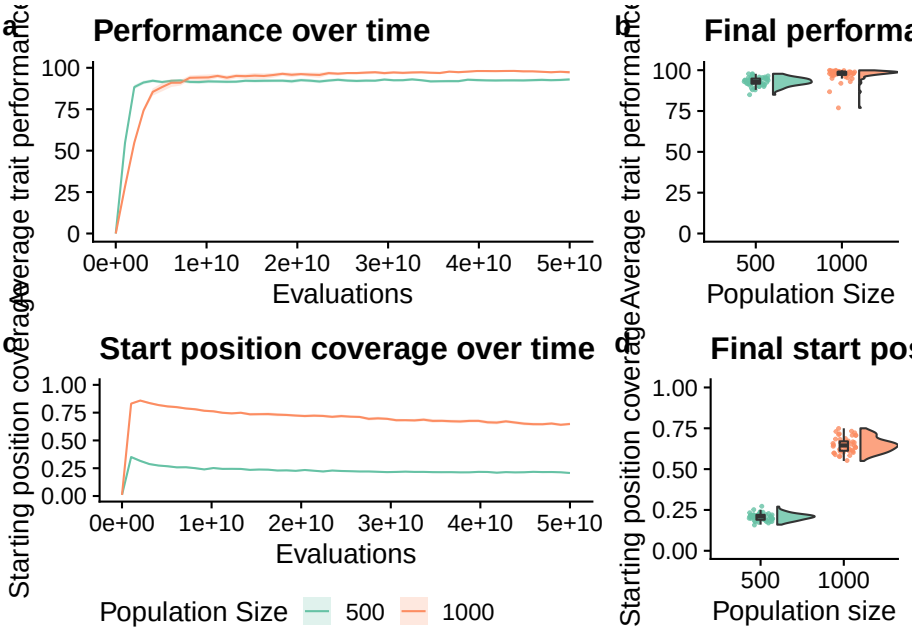
```
unique_start_positions_coverage_final_fig <- ggplot(
    final_data,
    aes(
      x=POP_SIZE,
      y=unique_start_positions_coverage,
      fill=POP_SIZE
    )
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=POP_SIZE),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
```

```
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0, 1.0)
  ) +
  scale_x_discrete(
    name="Population size"
  ) +
  scale_fill_brewer(
    name="Population size",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Population size",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
unique_start_positions_coverage_final_fig
```



6.6 Manuscript figures

```
grid <- plot_grid(
  elite_ave_performance_fig +
    ggtitle("Performance over time") +
    theme(legend.position="none"),
  elite_final_performance_fig +
    ggtitle("Final performance") +
    theme(),
  unique_start_position_coverage_fig +
    ggtitle("Start position coverage over time") +
    guides(
      color = guide_legend(nrow = 1),
      fill=guide_legend(nrow = 1)
    ) +
    theme(
      legend.position="bottom",
      legend.box="horizontal"
    ),
  unique_start_positions_coverage_final_fig +
    ggtitle("Final start position coverage") +
    theme(),
  nrow=2,
  ncol=2,
  rel_widths=c(2,1),
  labels="auto"
)

save_plot(
  paste(working_directory, "imgs/pop-size-panel.pdf", sep=""),
  grid,
  base_width=12,
  base_height=8
)

grid
```


A
Performance over time
Average trait performance
100
75
50
25
0
0e+00
1e+10
2e+10
3e+10
4e+10
5e+10
Evaluations
B
Final performa
Average trait performance
100
75
50
25
0
500
1000
Population Size
C
Start position coverage over time
Starting position coverage
1.00
0.75
0.50
0.25
0.00
0e+00
1e+10
2e+10
3e+10
4e+10
5e+10
Evaluations
Population Size
500
1000
D
Final start po
Starting position coverage
1.00
0.75
0.50
0.25
0.00
500
1000
Population size

Chapter 7

Epsilon lexicase

7.1 Overview

```
# Relative location of data.
working_directory <- "experiments/2021-05-28-epsilon/analysis/"
# working_directory <- "./"

# Settings for visualization
cb_palette <- "Set2"
# Create directory to dump plots
dir.create(paste0(working_directory, "imgs"), showWarnings=FALSE)
```

7.2 Analysis dependencies

```
library(ggplot2)
library(tidyverse)
library(cowplot)
library(viridis)
library(RColorBrewer)
source("https://gist.githubusercontent.com/benmarwick/2a1bb0133ff568cbe28d/raw/fb53bd97121f7f9ce9
```

These analyses were conducted in the following computing environment:

```
print(version)
```

```
##                _
## platform       x86_64-pc-linux-gnu
## arch           x86_64
## os             linux-gnu
```

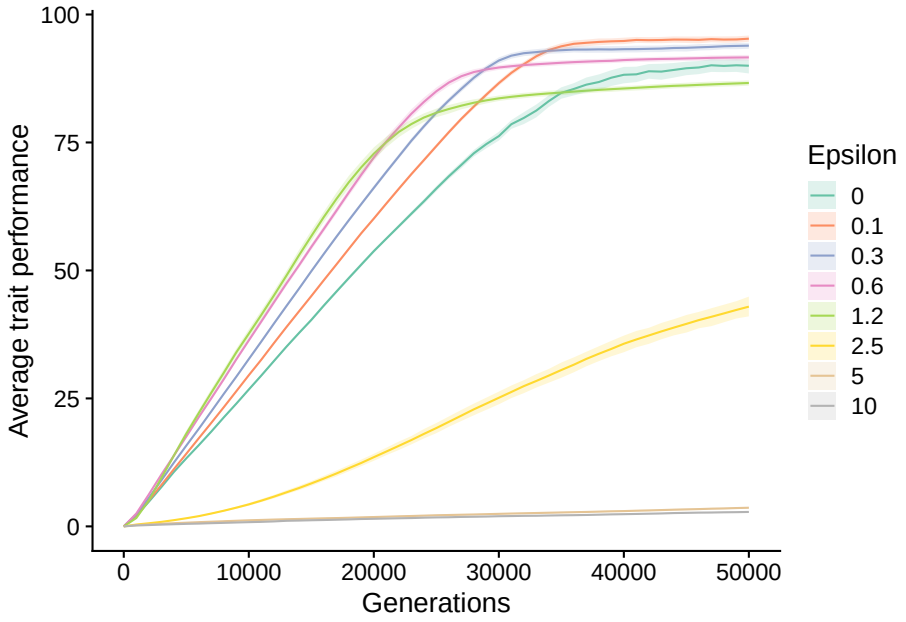
```
## system         x86_64, linux-gnu
## status
## major          4
## minor          1.0
## year           2021
## month          05
## day            18
## svn rev        80317
## language       R
## version.string R version 4.1.0 (2021-05-18)
## nickname       Camp Pontanezen
```

7.2 Setup

```
data_loc <- paste0(
  working_directory,
  "data/timeseries-res-1000g.csv"
)
data <- read.csv(data_loc, na.strings="NONE")

data$cardinality <- as.factor(
  data$OBJECTIVE_CNT
)
data$selection_name <- as.factor(
  data$selection_name
)

data$epsilon <- as.factor(
  data$LEX_EPS
)

data$elite_trait_avg <-
  data$ele_agg_per / data$OBJECTIVE_CNT
data$unique_start_positions_coverage <-
  data$uni_str_pos / data$OBJECTIVE_CNT

final_data <- filter(data, evaluations==max(data$evaluations))

####### misc #######
# Configure our default graphing theme
theme_set(theme_cowplot())
```

7.4 Exploration diagnostic performance

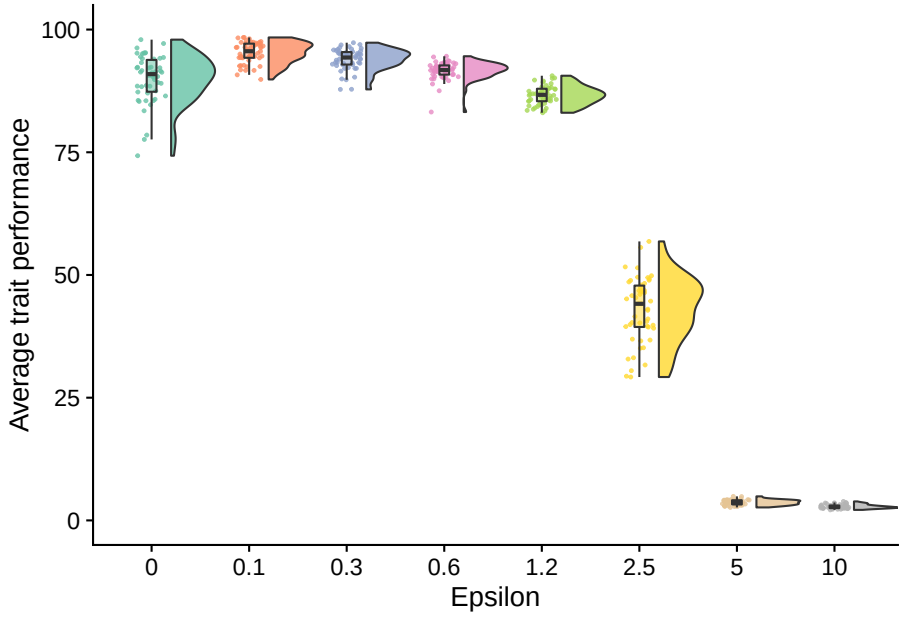
```
elite_ave_performance_fig <-
  ggplot(
    data,
    aes(x=gen, y=elite_trait_avg, color=epsilon, fill=epsilon)
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Average trait performance"
  ) +
  scale_x_continuous(
    name="Generations"
  ) +
  scale_fill_brewer(
    name="Epsilon",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Epsilon",
    palette=cb_palette
  )
elite_ave_performance_fig
```



7.4.1 Final performance

```
elite_final_performance_fig <- ggplot(
    final_data,
    aes(x=epsilon, y=elite_trait_avg, fill=epsilon)
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=epsilon),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Average trait performance",
```

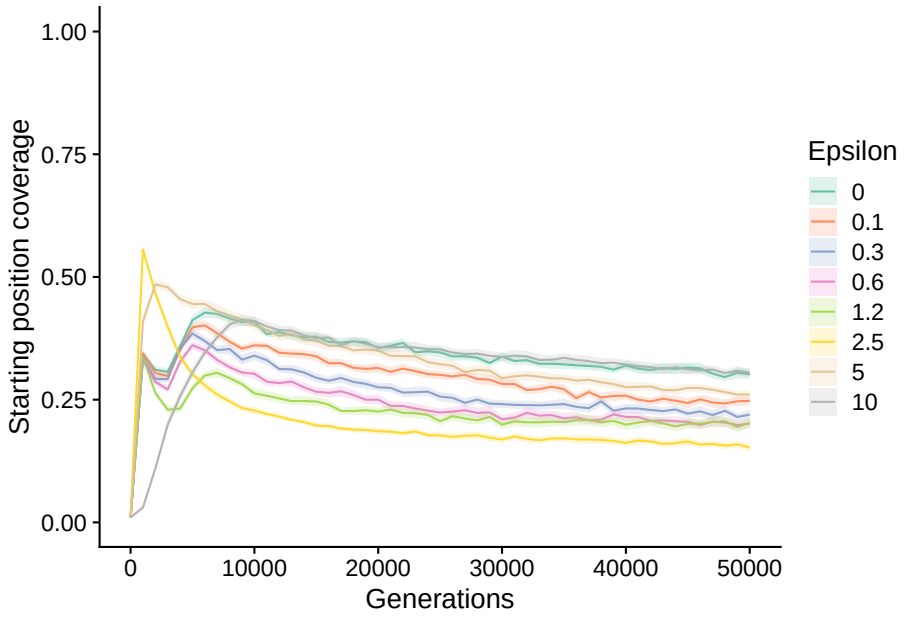
```
    limits=c(0, 100)
  ) +
  scale_x_discrete(
    name="Epsilon"
  ) +
  scale_fill_brewer(
    name="Epsilon",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Epsilon",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
elite_final_performance_fig
```



7.5 Unique starting positions

```
unique_start_position_coverage_fig <- ggplot(
    data,
    aes(
```

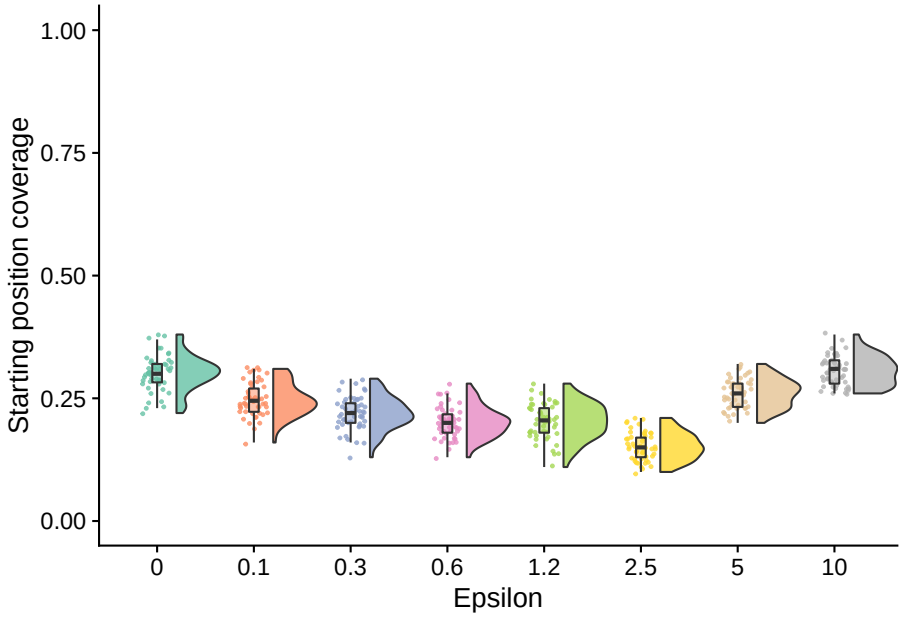
```
      x=gen,
      y=unique_start_positions_coverage,
      color=epsilon,
      fill=epsilon
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0.0, 1.0)
  ) +
  scale_x_continuous(
    name="Generations"
  ) +
  scale_fill_brewer(
    name="Epsilon",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Epsilon",
    palette=cb_palette
  )
unique_start_position_coverage_fig
```



7.5.1 Final coverage

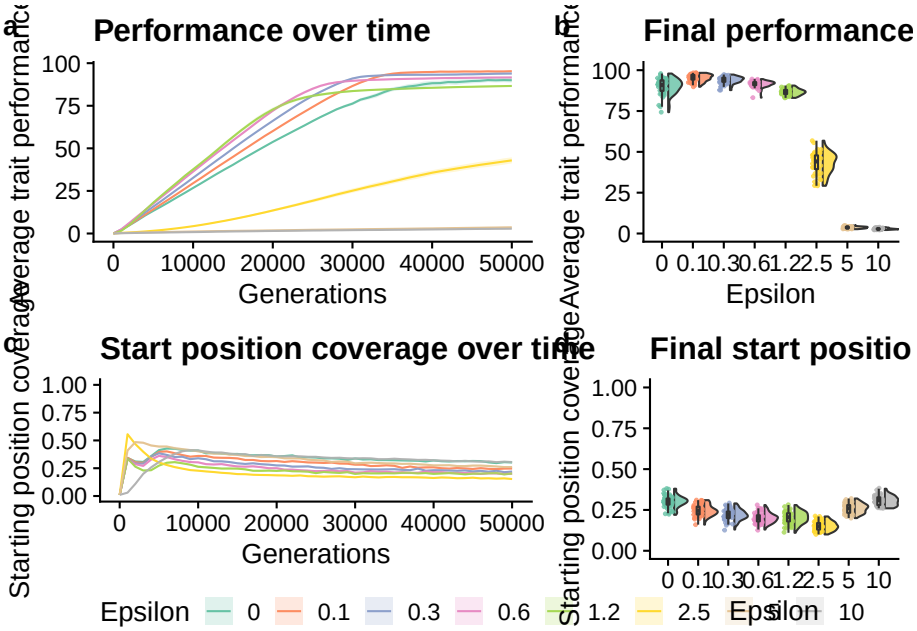
```
unique_start_positions_coverage_final_fig <- ggplot(
    final_data,
    aes(
      x=epsilon,
      y=unique_start_positions_coverage,
      fill=epsilon
    )
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=epsilon),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
```

```
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0, 1.0)
  ) +
  scale_x_discrete(
    name="Epsilon"
  ) +
  scale_fill_brewer(
    name="Epsilon",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Epsilon",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
unique_start_positions_coverage_final_fig
```



7.6 Manuscript figures

```
grid <- plot_grid(
  elite_ave_performance_fig +
    ggtitle("Performance over time") +
    theme(legend.position="none"),
  elite_final_performance_fig +
    ggtitle("Final performance") +
    theme(),
  unique_start_position_coverage_fig +
    ggtitle("Start position coverage over time") +
    guides(
      color = guide_legend(nrow = 1),
      fill=guide_legend(nrow = 1)
    ) +
    theme(
      legend.position="bottom",
      legend.box="horizontal"
    ),
  unique_start_positions_coverage_final_fig +
    ggtitle("Final start position coverage") +
    theme(),
  nrow=2,
  ncol=2,
  rel_widths=c(3,2),
  labels="auto"
)

save_plot(
  paste(working_directory, "imgs/epsilon-panel.pdf", sep=""),
  grid,
  base_width=12,
  base_height=8
)

grid
```


a
Performance over time
Average trait performance
100
75
50
25
0
0
10000
20000
30000
40000
50000
Generations
b
Final performance
Average trait performance
0 0.1 0.3 0.6 1.2 2.5 5 10
Epsilon
c
Start position coverage over time
Starting position coverage
1.00
0.75
0.50
0.25
0.00
Generations
d
Final start positio
Epsilon
Epsilon 0 0.1 0.3 0.6 1.2 2.5 5 10

Chapter 8

Down-sampled lexicase

8.1 Overview

```
# Relative location of data.
working_directory <- "experiments/2021-05-28-downsampled/analysis/"
# working_directory <- "./"

# Settings for visualization
cb_palette <- "Set2"
# Create directory to dump plots
dir.create(paste0(working_directory, "imgs"), showWarnings=FALSE)
```

8.2 Analysis dependencies

```
library(ggplot2)
library(tidyverse)
library(cowplot)
library(viridis)
library(RColorBrewer)
source("https://gist.githubusercontent.com/benmarwick/2a1bb0133ff568cbe28d/raw/fb53bd97121f7f9ce9
```

These analyses were conducted in the following computing environment:

```
print(version)
```

```
##                _
## platform       x86_64-pc-linux-gnu
## arch           x86_64
## os             linux-gnu
```

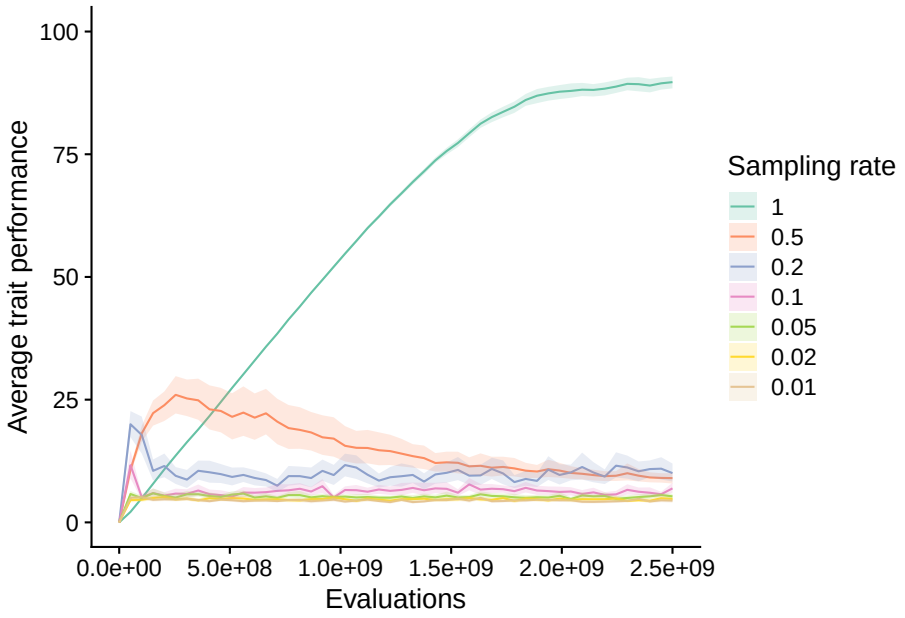
```
## system         x86_64, linux-gnu
## status
## major          4
## minor          1.0
## year           2021
## month          05
## day            18
## svn rev        80317
## language       R
## version.string R version 4.1.0 (2021-05-18)
## nickname       Camp Pontanezen
```

8.2 Setup

```
data_loc <- paste0(working_directory, "data/timeseries.csv")
data <- read.csv(data_loc, na.strings="NONE")

data$cardinality <- as.factor(
  data$OBJECTIVE_CNT
)
data$selection_name <- as.factor(
  data$selection_name
)

data$epsilon <- as.factor(
  data$LEX_EPS
)

data$proportion <- factor(
  data$DSLEX_PROP,
  levels=c(1, 0.5, 0.2, 0.1, 0.05, 0.02, 0.01)
)

data$elite_trait_avg <- data$ele_agg_per / data$OBJECTIVE_CNT
data$unique_start_positions_coverage <- data$uni_str_pos / data$OBJECTIVE_CNT

final_data <- filter(data, evaluations==max(data$evaluations))

####### misc #######
# Configure our default graphing theme
theme_set(theme_cowplot())
```

8.4 Exploration diagnostic performance

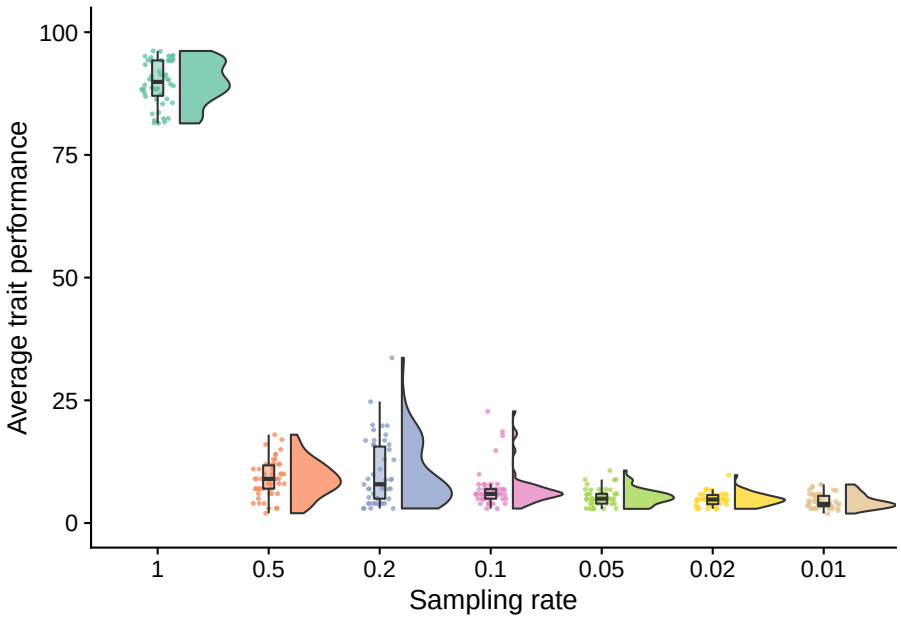
```
elite_ave_performance_fig <-
  ggplot(
    data,
    aes(
      x=evaluations,
      y=elite_trait_avg,
      color=proportion,
      fill=proportion
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Average trait performance",
    limits=c(0, 100)
  ) +
  scale_x_continuous(
    name="Evaluations"
  ) +
  scale_fill_brewer(
    name="Sampling rate",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Sampling rate",
    palette=cb_palette
  )
elite_ave_performance_fig
```



8.4.1 Final performance

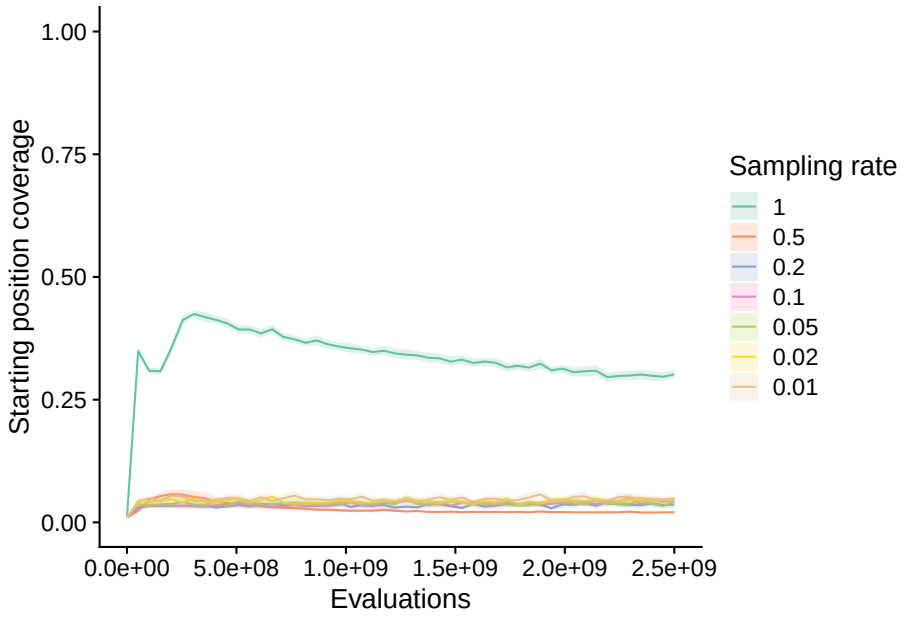
```
elite_final_performance_fig <- ggplot(
    final_data,
    aes(
      x=proportion,
      y=elite_trait_avg,
      fill=proportion
    )
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=proportion),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
```

```
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Average trait performance",
    limits=c(0, 100)
  ) +
  scale_x_discrete(
    name="Sampling rate"
  ) +
  scale_fill_brewer(
    name="Sampling rate",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Sampling rate",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
elite_final_performance_fig
```



8.5 Unique starting positions

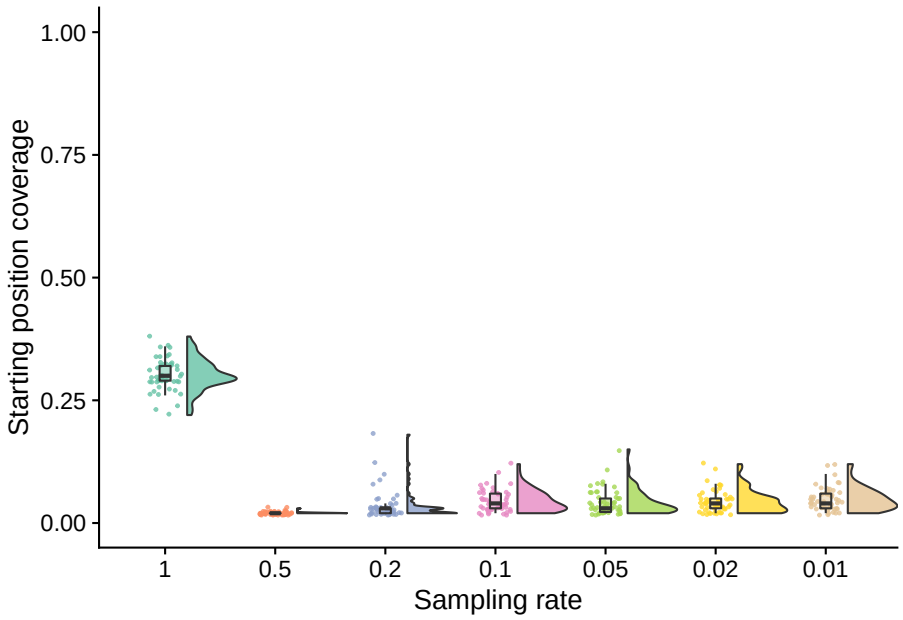
```
unique_start_position_coverage_fig <- ggplot(
    data,
    aes(
      x=evaluations,
      y=unique_start_positions_coverage,
      color=proportion,
      fill=proportion
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0.0, 1.0)
  ) +
  scale_x_continuous(
    name="Evaluations"
  ) +
  scale_fill_brewer(
    name="Sampling rate",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Sampling rate",
    palette=cb_palette
  )
unique_start_position_coverage_fig
```



8.5.1 Final starting position coverage

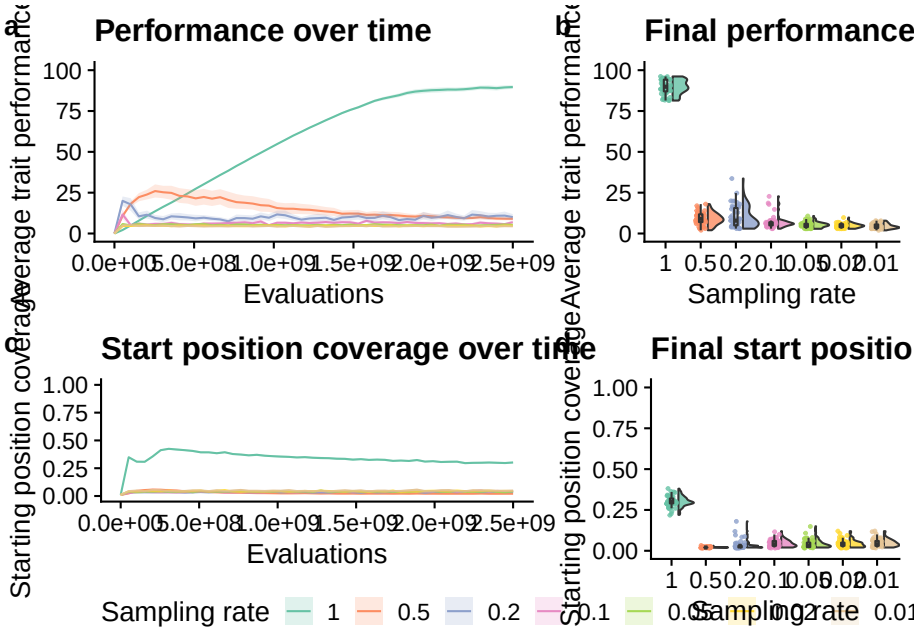
```
unique_start_positions_coverage_final_fig <- ggplot(
    final_data,
    aes(
      x=proportion,
      y=unique_start_positions_coverage,
      fill=proportion
    )
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=proportion),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
```

```
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0, 1.0)
  ) +
  scale_x_discrete(
    name="Sampling rate"
  ) +
  scale_fill_brewer(
    name="Sampling rate",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Sampling rate",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
unique_start_positions_coverage_final_fig
```



8.6 Manuscript figures

```
grid <- plot_grid(
  elite_ave_performance_fig +
    ggtitle("Performance over time") +
    theme(legend.position="none"),
  elite_final_performance_fig +
    ggtitle("Final performance") +
    theme(),
  unique_start_position_coverage_fig +
    ggtitle("Start position coverage over time") +
    guides(
      color = guide_legend(nrow = 1),
      fill=guide_legend(nrow = 1)
    ) +
    theme(
      legend.position="bottom",
      legend.box="horizontal"
    ),
  unique_start_positions_coverage_final_fig +
    ggtitle("Final start position coverage") +
    theme(),
  nrow=2,
  ncol=2,
  rel_widths=c(3,2),
  labels="auto"
)

save_plot(
  paste(working_directory, "imgs/down-sampled-panel.pdf", sep=""),
  grid,
  base_width=12,
  base_height=8
)

grid
```


a
Performance over time
Average trait performance
100
75
50
25
0
0.0e+00
5.0e+08
1.0e+09
1.5e+09
2.0e+09
2.5e+09
Evaluations
b
Final performance
Average trait performance
100
75
50
25
0
1
0.5
0.2
0.1
0.05
0.02
0.01
Sampling rate
c
Start position coverage over time
Starting position coverage
1.00
0.75
0.50
0.25
0.00
0.0e+00
5.0e+08
1.0e+09
1.5e+09
2.0e+09
2.5e+09
Evaluations
d
Final start positio
Starting position coverage
1.00
0.75
0.50
0.25
0.00
1
0.5
0.2
0.1
0.05
0.02
0.01
Sampling rate
Sampling rate
1
0.5
0.2
0.1
0.05
0.02
0.01

Chapter 9

Cohort lexicase

9.1 Overview

```
# Relative location of data.
working_directory <- "experiments/2021-06-01-cohort/analysis/"
# working_directory <- "./"

# Settings for visualization
cb_palette <- "Set2"
# Create directory to dump plots
dir.create(paste0(working_directory, "imgs"), showWarnings=FALSE)
```

9.2 Analysis dependencies

```
library(ggplot2)
library(tidyverse)
library(cowplot)
library(viridis)
library(RColorBrewer)
source("https://gist.githubusercontent.com/benmarwick/2a1bb0133ff568cbe28d/raw/fb53bd97121f7f9ce9
```

These analyses were conducted in the following computing environment:

```
print(version)
```

```
##                _
## platform       x86_64-pc-linux-gnu
## arch           x86_64
## os             linux-gnu
```

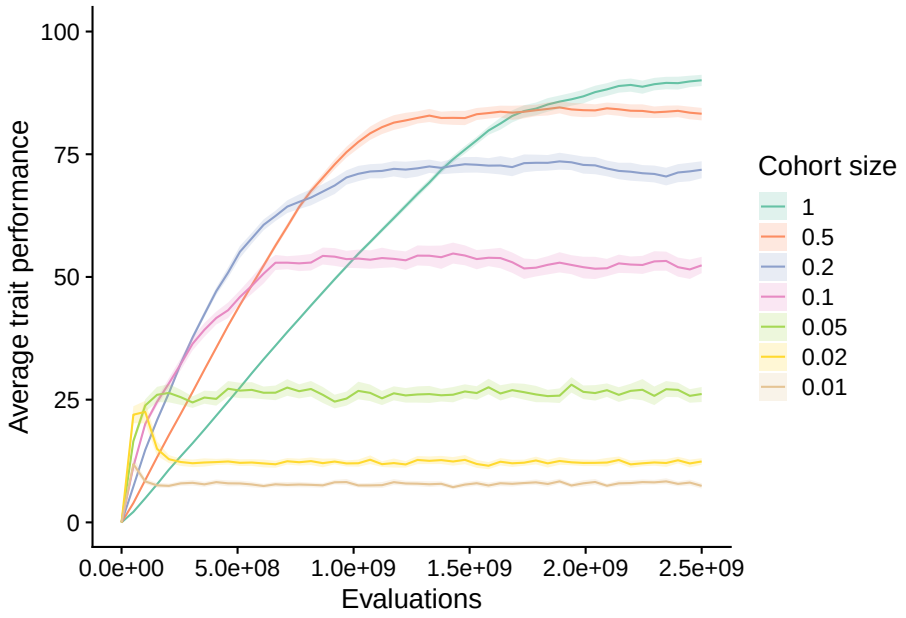
```
## system         x86_64, linux-gnu
## status
## major          4
## minor          1.0
## year           2021
## month          05
## day            18
## svn rev        80317
## language       R
## version.string R version 4.1.0 (2021-05-18)
## nickname       Camp Pontanezen
```

9.3 Setup

```
data_loc <- paste0(working_directory, "data/timeseries.csv")
data <- read.csv(data_loc, na.strings="NONE")

data$cardinality <- as.factor(
  data$OBJECTIVE_CNT
)
data$selection_name <- as.factor(
  data$selection_name
)

data$epsilon <- as.factor(
  data$LEX_EPS
)

data$proportion <- factor(
  data$COH_LEX_PROP,
  levels=c(1, 0.5, 0.2, 0.1, 0.05, 0.02, 0.01)
)

data$elite_trait_avg <-
  data$ele_agg_per / data$OBJECTIVE_CNT
data$unique_start_positions_coverage <-
  data$uni_str_pos / data$OBJECTIVE_CNT

final_data <- filter(data, evaluations==max(data$evaluations))

####### misc #######
# Configure our default graphing theme
theme_set(theme_cowplot())
```

9.4 Exploration diagnostic performance

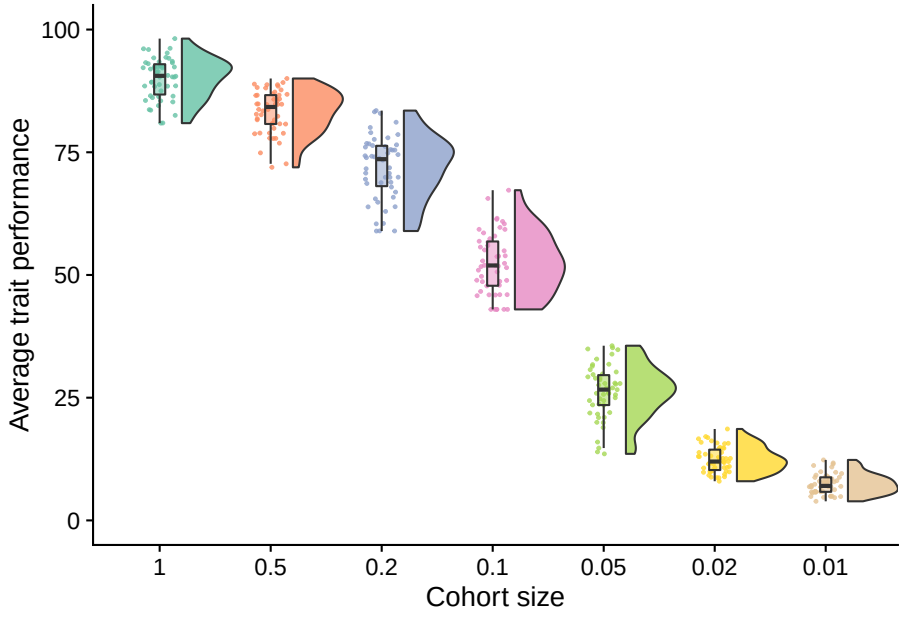
```
elite_ave_performance_fig <-
  ggplot(
    data,
    aes(
      x=evaluations,
      y=elite_trait_avg,
      color=proportion,
      fill=proportion
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Average trait performance",
    limits=c(0, 100)
  ) +
  scale_x_continuous(
    name="Evaluations"
  ) +
  scale_fill_brewer(
    name="Cohort size",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Cohort size",
    palette=cb_palette
  )
elite_ave_performance_fig
```



9.4.1 Final performance

```
elite_final_performance_fig <- ggplot(
    final_data,
    aes(x=proportion, y=elite_trait_avg, fill=proportion)
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=proportion),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Average trait performance",
```

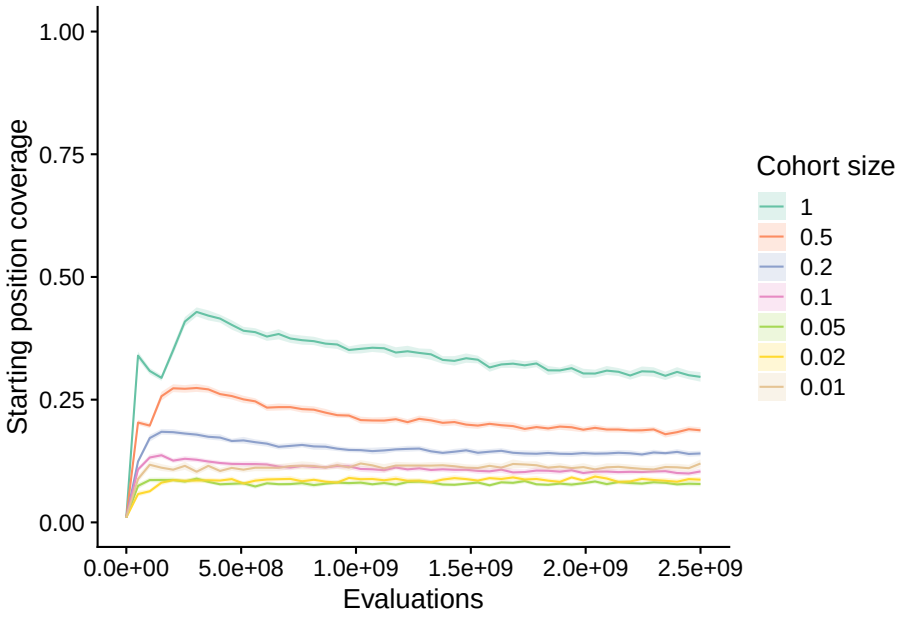
```
    limits=c(0, 100)
  ) +
  scale_x_discrete(
    name="Cohort size"
  ) +
  scale_fill_brewer(
    name="Cohort size",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Cohort size",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
elite_final_performance_fig
```



9.5 Unique starting positions

```
unique_start_position_coverage_fig <- ggplot(
    data,
    aes(
```

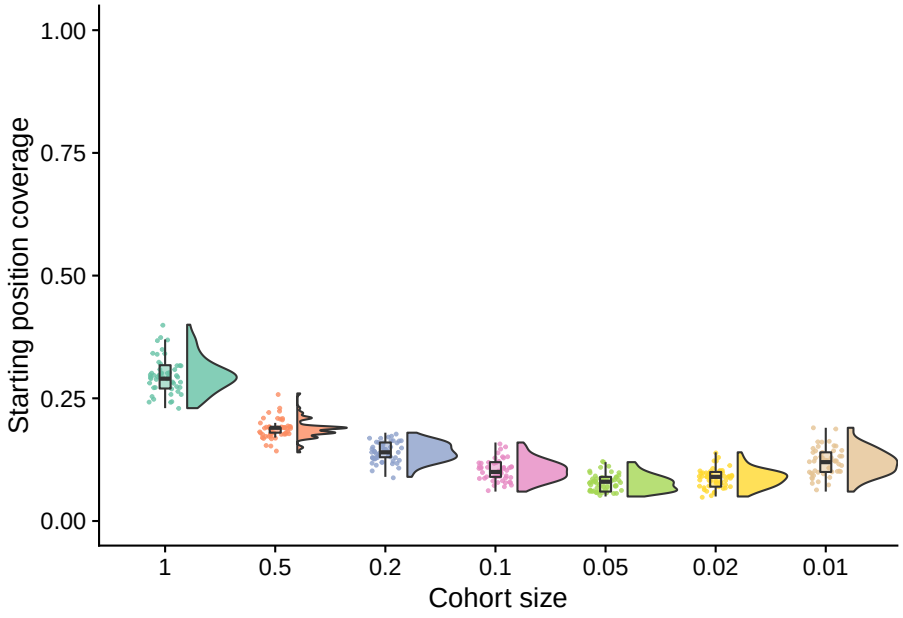
```
      x=evaluations,
      y=unique_start_positions_coverage,
      color=proportion,
      fill=proportion
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0.0, 1.0)
  ) +
  scale_x_continuous(
    name="Evaluations"
  ) +
  scale_fill_brewer(
    name="Cohort size",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Cohort size",
    palette=cb_palette
  )
unique_start_position_coverage_fig
```



9.5.1 Final starting position coverage

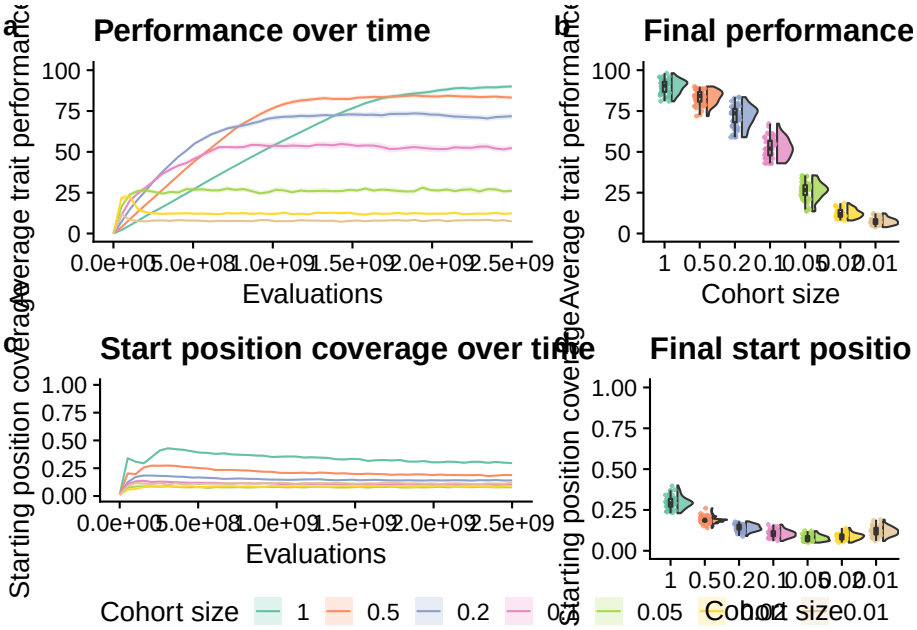
```
unique_start_positions_coverage_final_fig <- ggplot(
    final_data,
    aes(
      x=proportion,
      y=unique_start_positions_coverage,
      fill=proportion
    )
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=proportion),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
```

```
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0, 1.0)
  ) +
  scale_x_discrete(
    name="Cohort size"
  ) +
  scale_fill_brewer(
    name="Cohort size",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="Cohort size",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
unique_start_positions_coverage_final_fig
```



9.6 Manuscript figures

```
grid <- plot_grid(
  elite_ave_performance_fig +
    ggtitle("Performance over time") +
    theme(legend.position="none"),
  elite_final_performance_fig +
    ggtitle("Final performance") +
    theme(),
  unique_start_position_coverage_fig +
    ggtitle("Start position coverage over time") +
    guides(
      color = guide_legend(nrow = 1),
      fill=guide_legend(nrow = 1)
    ) +
    theme(
      legend.position="bottom",
      legend.box="horizontal"
    ),
  unique_start_positions_coverage_final_fig +
    ggtitle("Final start position coverage") +
    theme(),
  nrow=2,
  ncol=2,
  rel_widths=c(3,2),
  labels="auto"
)

save_plot(
  paste(working_directory, "imgs/cohort-panel.pdf", sep=""),
  grid,
  base_width=12,
  base_height=8
)

grid
```


a
Performance over time
Average trait performanc
100
75
50
25
0
0.0e+00
5.0e+08
1.0e+09
1.5e+09
2.0e+09
2.5e+09
Evaluations
b
Final performance
Average trait performanc
100
75
50
25
0
1
0.5
0.2
0.1
0.05
0.02
0.01
Cohort size
c
Start position coverage over time
Starting position coverage
1.00
0.75
0.50
0.25
0.00
0.0e+00
5.0e+08
1.0e+09
1.5e+09
2.0e+09
2.5e+09
Evaluations
d
Final start positio
Starting position coverage
1.00
0.75
0.50
0.25
0.00
1
0.5
0.2
0.1
0.05
0.02
0.01
Cohort size
Cohort size
1
0.5
0.2
0.1
0.05
0.02
0.01

Chapter 10

Down-sampled lexicase versus cohort lexicase

10.1 Overview

```
# Relative location of data.
working_directory <-
  "experiments/2021-06-05-downsample-vs-cohort/analysis/"
# working_directory <- "./"

# Settings for visualization
cb_palette <- "Dark2"
# Create directory to dump plots
dir.create(paste0(working_directory, "imgs"), showWarnings=FALSE)
```

10.2 Analysis dependencies

```
library(ggplot2)
library(tidyverse)
library(cowplot)
library(viridis)
library(RColorBrewer)
source("https://gist.githubusercontent.com/benmarwick/2a1bb0133ff568cbe28d/raw/fb53bd97121f7f9ce9
```

These analyses were conducted in the following computing environment:

```
print(version)
```

```
##                _
```

```
## platform       x86_64-pc-linux-gnu
## arch           x86_64
## os             linux-gnu
## system         x86_64, linux-gnu
## status
## major          4
## minor          1.0
## year           2021
## month          05
## day            18
## svn rev        80317
## language       R
## version.string R version 4.1.0 (2021-05-18)
## nickname       Camp Pontanezen
```

10.3 Setup

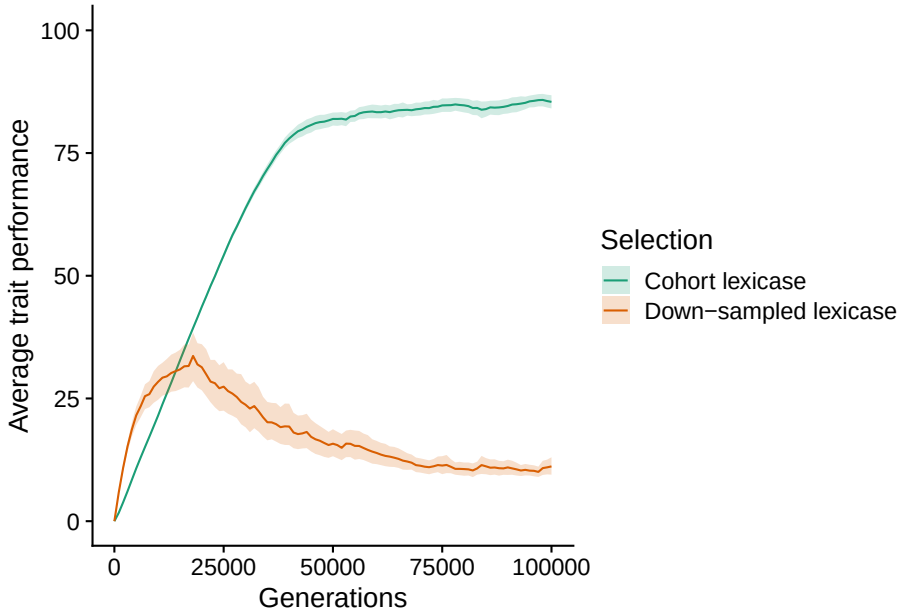
```
data_loc <- paste0(working_directory, "data/timeseries.csv")
data <- read.csv(data_loc, na.strings="NONE")

data$cardinality <- as.factor(
  data$OBJECTIVE_CNT
)
data$selection_name <- as.factor(
  data$selection_name
)

data$epsilon <- as.factor(
  data$LEX_EPS
)

# I always set cohort and downsampled lexicase sampling rates to
# be the same on a given run (regardless of selection scheme)
data$proportion <- factor(
  data$COH_LEX_PROP,
  levels=c(1, 0.5, 0.2, 0.1, 0.05, 0.02, 0.01)
)

data$elite_trait_avg <-
  data$ele_agg_per / data$OBJECTIVE_CNT
data$unique_start_positions_coverage <-
  data$uni_str_pos / data$OBJECTIVE_CNT

final_data <- filter(data, evaluations==max(data$evaluations))
```

```
####### misc #######
# Configure our default graphing theme
theme_set(theme_cowplot())
```

10.4 Exploration diagnostic performance

```
elite_ave_performance_fig <-
  ggplot(
    data,
    aes(
      x=gen,
      y=elite_trait_avg,
      color=selection_name,
      fill=selection_name
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Average trait performance",
    limits=c(0, 100)
  ) +
  scale_x_continuous(
    name="Generations"
  ) +
  scale_fill_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("CohortLexicase", "DownSampledLexicase"),
    labels=c("Cohort lexicase", "Down-sampled lexicase")
  ) +
  scale_color_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("CohortLexicase", "DownSampledLexicase"),
    labels=c("Cohort lexicase", "Down-sampled lexicase")
  )
```

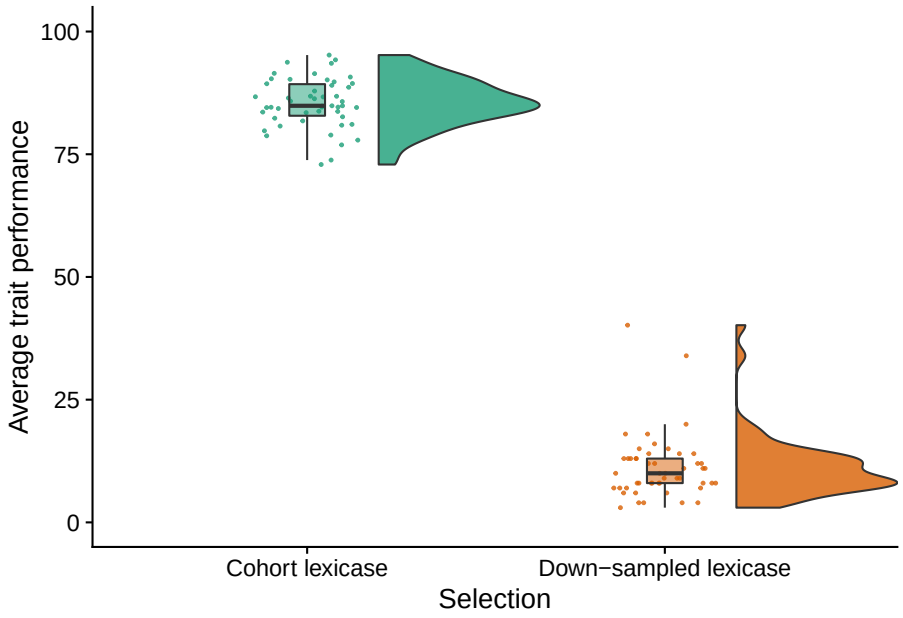
```
elite_ave_performance_fig
```



10.4.1 Final performance

```
elite_final_performance_fig <- ggplot(
    final_data,
    aes(x=selection_name, y=elite_trait_avg, fill=selection_name)
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=selection_name),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
    alpha = 0.5
  ) +
```

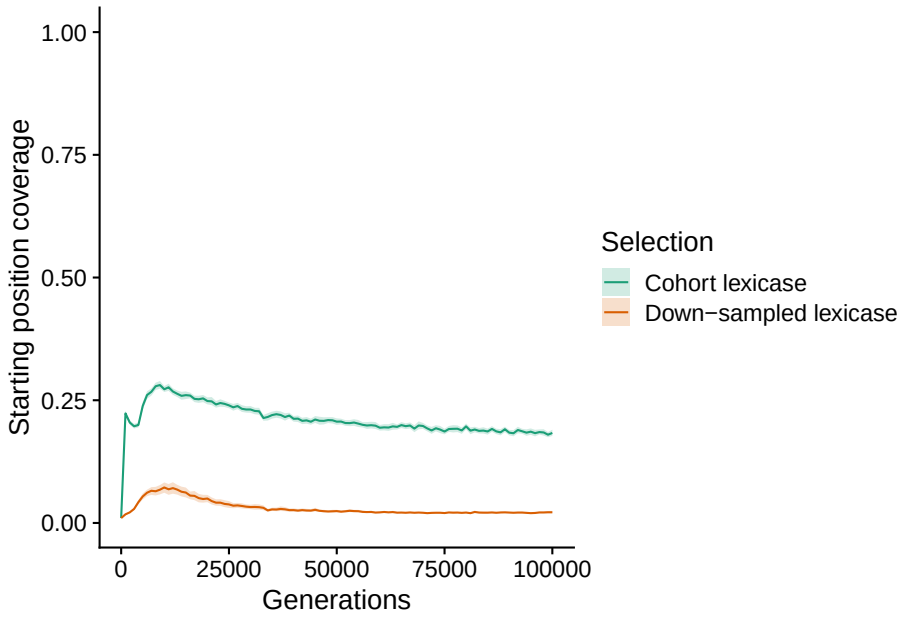
```
  scale_y_continuous(
    name="Average trait performance",
    limits=c(0, 100)
  ) +
  scale_x_discrete(
    name="Selection",
    limits=c("CohortLexicase", "DownSampledLexicase"),
    labels=c("Cohort lexicase", "Down-sampled lexicase")
  ) +
  scale_fill_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("CohortLexicase", "DownSampledLexicase"),
    labels=c("Cohort lexicase", "Down-sampled lexicase")
  ) +
  scale_color_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("CohortLexicase", "DownSampledLexicase"),
    labels=c("Cohort lexicase", "Down-sampled lexicase")
  ) +
  theme(
    legend.position="none"
  )
elite_final_performance_fig
```



10.5 Unique starting positions

```
unique_start_position_coverage_fig <- ggplot(
    data,
    aes(
      x=gen,
      y=unique_start_positions_coverage,
      color=selection_name,
      fill=selection_name
    )
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0.0, 1.0)
  ) +
```

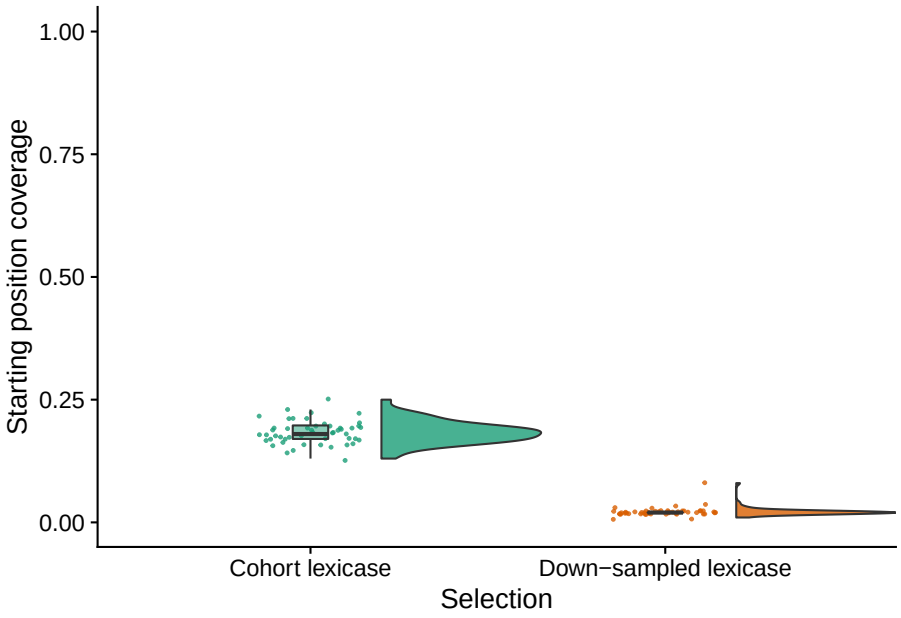
```
  scale_x_continuous(
    name="Generations"
  ) +
  scale_fill_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("CohortLexicase", "DownSampledLexicase"),
    labels=c("Cohort lexicase", "Down-sampled lexicase")

  ) +
  scale_color_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("CohortLexicase", "DownSampledLexicase"),
    labels=c("Cohort lexicase", "Down-sampled lexicase")
  )
unique_start_position_coverage_fig
```



10.5.1 Final starting position coverage

```
unique_start_positions_coverage_final_fig <- ggplot(
    final_data,
    aes(
      x=selection_name,
```

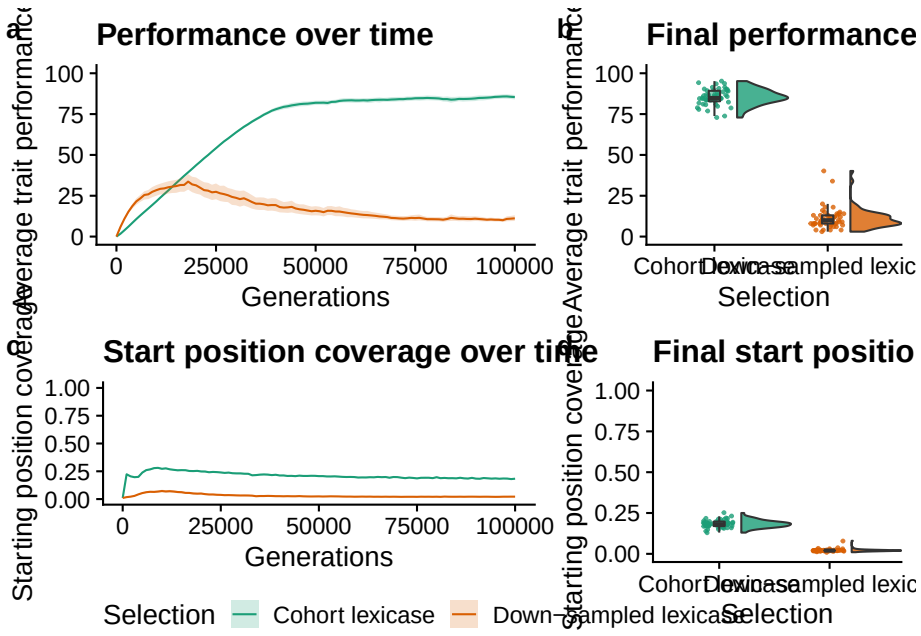
```
      y=unique_start_positions_coverage,
      fill=selection_name
    )
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=selection_name),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0, 1.0)
  ) +
  scale_x_discrete(
    name="Selection",
    limits=c("CohortLexicase", "DownSampledLexicase"),
    labels=c("Cohort lexicase", "Down-sampled lexicase")
  ) +
  scale_fill_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("CohortLexicase", "DownSampledLexicase"),
    labels=c("Cohort lexicase", "Down-sampled lexicase")
  ) +
  scale_color_brewer(
    name="Selection",
    palette=cb_palette,
    limits=c("CohortLexicase", "DownSampledLexicase"),
    labels=c("Cohort lexicase", "Down-sampled lexicase")
  ) +
  theme(
    legend.position="none"
  )
unique_start_positions_coverage_final_fig
```



10.6 Manuscript figures

```
grid <- plot_grid(
  elite_ave_performance_fig +
    ggtitle("Performance over time") +
    theme(legend.position="none"),
  elite_final_performance_fig +
    ggtitle("Final performance") +
    theme(),
  unique_start_position_coverage_fig +
    ggtitle("Start position coverage over time") +
    guides(
      color = guide_legend(nrow = 1),
      fill=guide_legend(nrow = 1)
    ) +
    theme(
      legend.position="bottom",
      legend.box="horizontal"
    ),
  unique_start_positions_coverage_final_fig +
    ggtitle("Final start position coverage") +
    theme(),
  nrow=2,
```

```
  ncol=2,
  rel_widths=c(3,2),
  labels="auto"
)

save_plot(
  paste(
    working_directory,
    "imgs/down-sampled-vs-cohort-panel.pdf",
    sep=""
  ),
  grid,
  base_width=12,
  base_height=8
)

grid
```



Chapter 11

Novelty lexicase

11.1 Overview

```
# Relative location of data.
working_directory <- "experiments/2021-06-01-novelty/analysis/"
# working_directory <- "./"

# Settings for visualization
cb_palette <- "Set2"
# Create directory to dump plots
dir.create(paste0(working_directory, "imgs"), showWarnings=FALSE)
```

11.2 Analysis dependencies

```
library(ggplot2)
library(tidyverse)
library(cowplot)
library(viridis)
library(RColorBrewer)
source("https://gist.githubusercontent.com/benmarwick/2a1bb0133ff568cbe28d/raw/fb53bd97121f7f9ce9
```

These analyses were conducted in the following computing environment:

```
print(version)
```

```
##                _
## platform       x86_64-pc-linux-gnu
## arch           x86_64
## os             linux-gnu
```

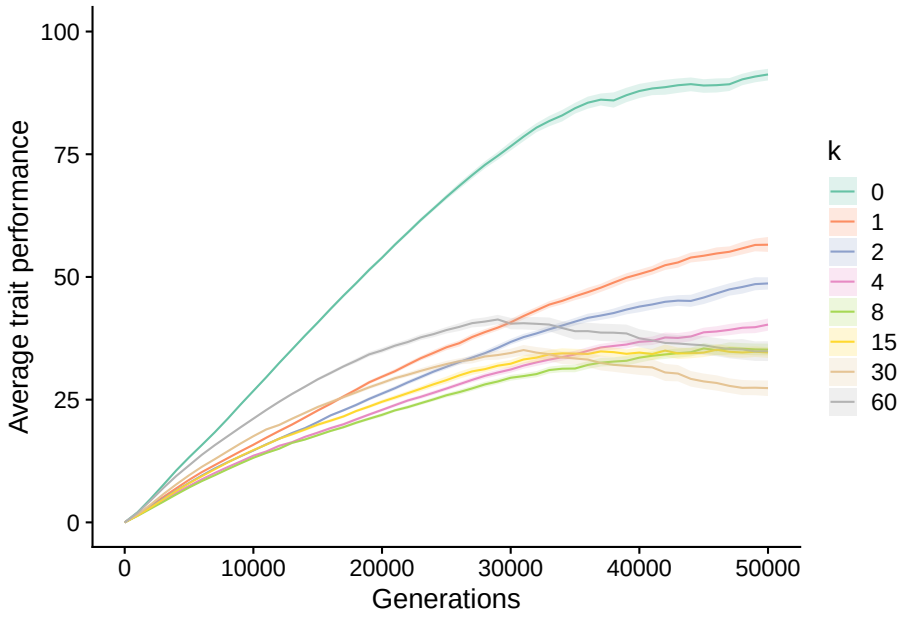
```
## system         x86_64, linux-gnu
## status
## major          4
## minor          1.0
## year           2021
## month          05
## day            18
## svn rev        80317
## language       R
## version.string R version 4.1.0 (2021-05-18)
## nickname       Camp Pontanezen
```

11.3 Setup

```
data_loc <- paste0(
  working_directory,
  "data/timeseries-res-1000g.csv"
)

data <- read.csv(data_loc, na.strings="NONE")

data$cardinality <- as.factor(
  data$OBJECTIVE_CNT
)
data$selection_name <- as.factor(
  data$selection_name
)

data$epsilon <- as.factor(
  data$LEX_EPS
)

data$k <- as.factor(
   data$NOVEL_K
)

data$elite_trait_avg <-
  data$ele_agg_per / data$OBJECTIVE_CNT
data$unique_start_positions_coverage <-
  data$uni_str_pos / data$OBJECTIVE_CNT

final_data <- filter(data, evaluations==max(data$evaluations))

####### misc #######
```

```
# Configure our default graphing theme
theme_set(theme_cowplot())
```

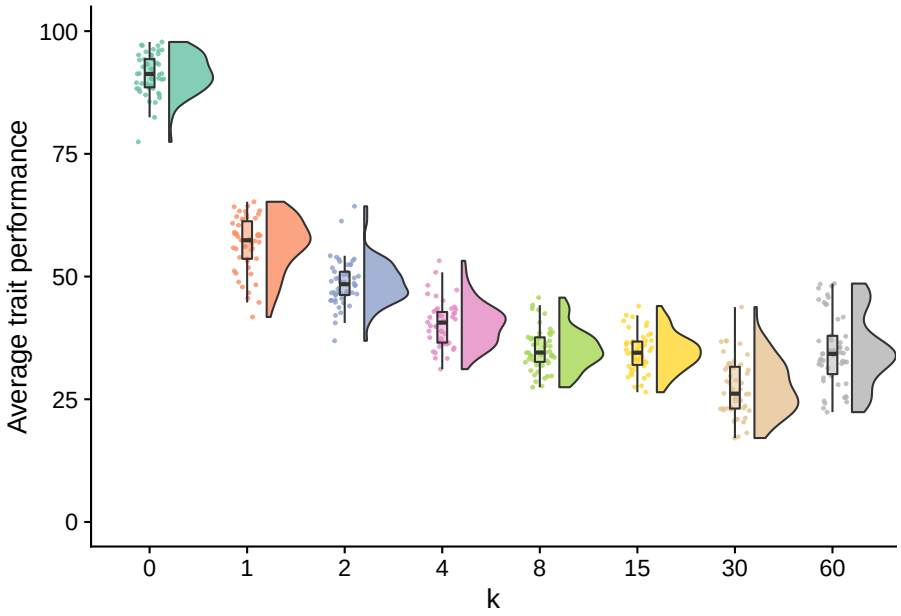
```
elite_ave_performance_fig <-
  ggplot(
    data,
    aes(x=gen, y=elite_trait_avg, color=k, fill=k)
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Average trait performance",
    limits=c(0, 100)
  ) +
  scale_x_continuous(
    name="Generations"
  ) +
  scale_fill_brewer(
    name="k",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="k",
    palette=cb_palette
  )
elite_ave_performance_fig
```



11.4.1 Final performance

```
elite_final_performance_fig <- ggplot(
    final_data,
    aes(x=k, y=elite_trait_avg, fill=k)
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=k),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Average trait performance",
```

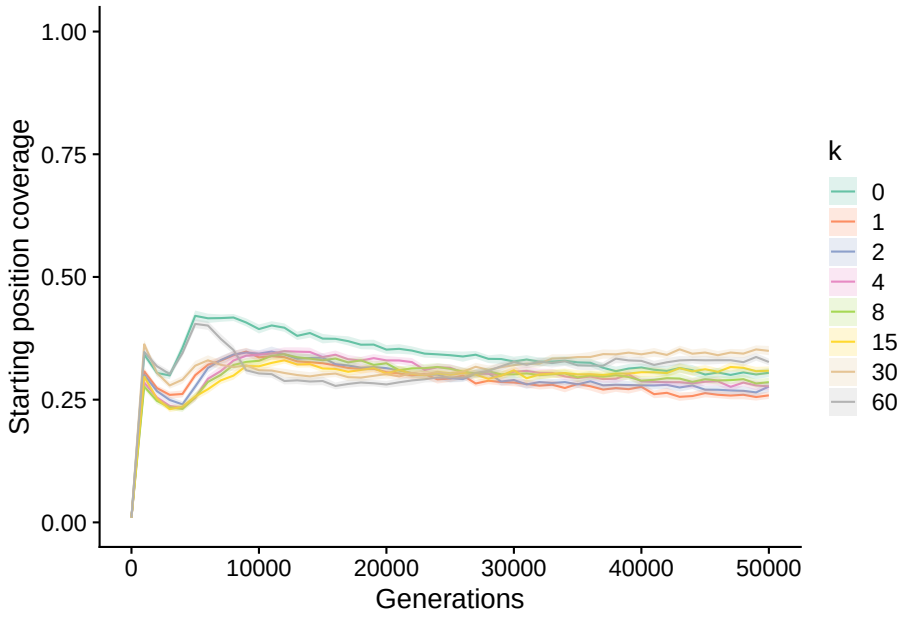
```
    limits=c(0, 100)
  ) +
  scale_x_discrete(
    name="k"
  ) +
  scale_fill_brewer(
    name="k",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="k",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
elite_final_performance_fig
```



11.5 Unique starting positions

```
unique_start_position_coverage_fig <- ggplot(
    data,
    aes(x=gen, y=unique_start_positions_coverage, color=k, fill=k)
```

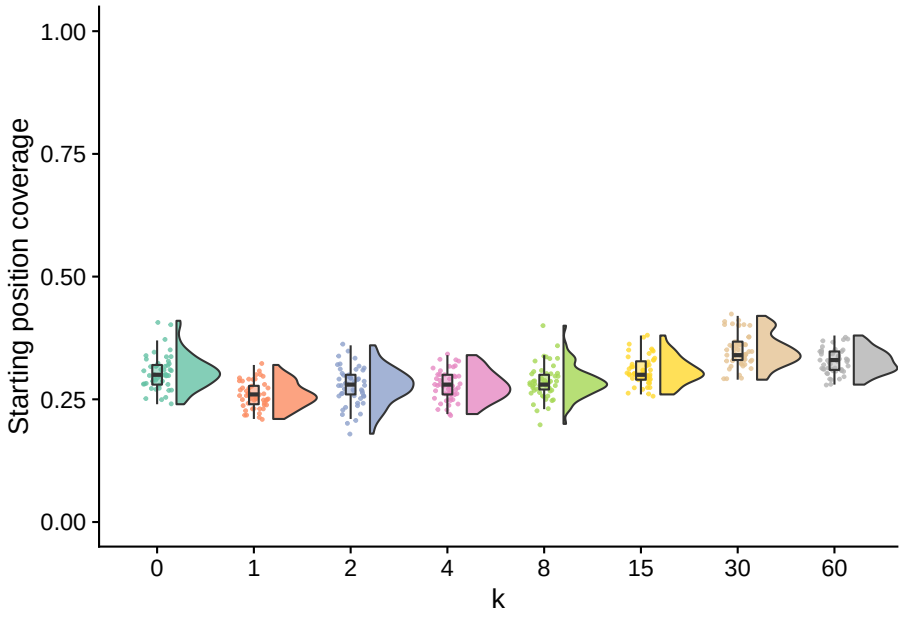
```
  ) +
  stat_summary(geom="line", fun=mean) +
  stat_summary(
    geom="ribbon",
    fun.data="mean_cl_boot",
    fun.args=list(conf.int=0.95),
    alpha=0.2,
    linetype=0
  ) +
  scale_y_continuous(
    name="Starting position coverage",
    limits=c(0.0, 1.0)
  ) +
  scale_x_continuous(
    name="Generations"
  ) +
  scale_fill_brewer(
    name="k",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="k",
    palette=cb_palette
  )
unique_start_position_coverage_fig
```



11.5.1 Final starting position coverage

```
unique_start_positions_coverage_final_fig <- ggplot(
    final_data,
    aes(x=k, y=unique_start_positions_coverage, fill=k)
  ) +
  geom_flat_violin(
    position = position_nudge(x = .2, y = 0),
    alpha = .8,
    scale="width"
  ) +
  geom_point(
    mapping=aes(color=k),
    position = position_jitter(width = .15),
    size = .5,
    alpha = 0.8
  ) +
  geom_boxplot(
    width = .1,
    outlier.shape = NA,
    alpha = 0.5
  ) +
  scale_y_continuous(
    name="Starting position coverage",
```

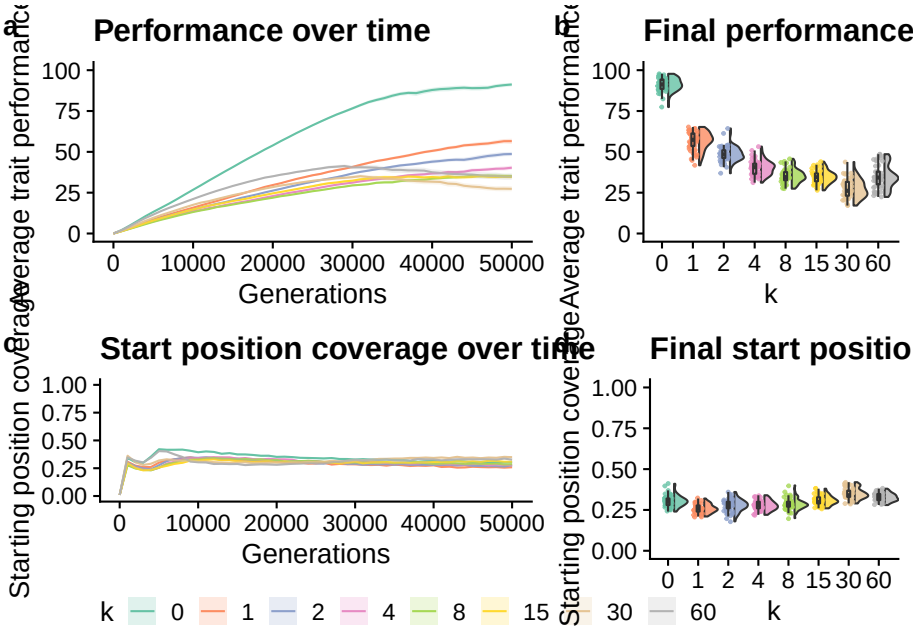
```
    limits=c(0, 1.0)
  ) +
  scale_x_discrete(
    name="k"
  ) +
  scale_fill_brewer(
    name="k",
    palette=cb_palette
  ) +
  scale_color_brewer(
    name="k",
    palette=cb_palette
  ) +
  theme(
    legend.position="none"
  )
unique_start_positions_coverage_final_fig
```



11.6 Manuscript figures

```
grid <- plot_grid(
  elite_ave_performance_fig +
    ggtitle("Performance over time") +
```

```
    theme(legend.position="none"),
  elite_final_performance_fig +
    ggtitle("Final performance") +
    theme(),
  unique_start_position_coverage_fig +
    ggtitle("Start position coverage over time") +
    guides(
      color=guide_legend(nrow = 1),
      fill=guide_legend(nrow = 1)
    ) +
    theme(
      legend.position="bottom",
      legend.box="horizontal"
    ),
  unique_start_positions_coverage_final_fig +
    ggtitle("Final start position coverage") +
    theme(),
  nrow=2,
  ncol=2,
  rel_widths=c(3,2),
  labels="auto"
)

save_plot(
  paste(working_directory, "imgs/novelty-panel.pdf", sep=""),
  grid,
  base_width=12,
  base_height=8
)

grid
```


a
Performance over time
Average trait performance
100
75
50
25
0
0
10000
20000
30000
40000
50000
Generations
b
Final performance
Average trait performance
100
75
50
25
0
0
1
2
4
8
15
30
60
k
c
Start position coverage over time
Starting position coverage
1.00
0.75
0.50
0.25
0.00
0
10000
20000
30000
40000
50000
Generations
d
Final start positio
Starting position coverage
1.00
0.75
0.50
0.25
0.00
0
1
2
4
8
15
30
60
k
k
0
1
2
4
8
15
30
60

Bibliography

Lalejini, A. M. and Hernandez, J. G. (2021). Data for measuring the ability of lexicase selection to find obscure pathways to optimality.