React Alicante

Evolving Game Development with Genetic Algorithms

Kevin Maes

2024

STATELY

Kevin Maes

MUSEO VIDEOJUEGO
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OXO STORE
OXO STORE
PLAZA DEL SIGLO
Spanish School
Unicaja
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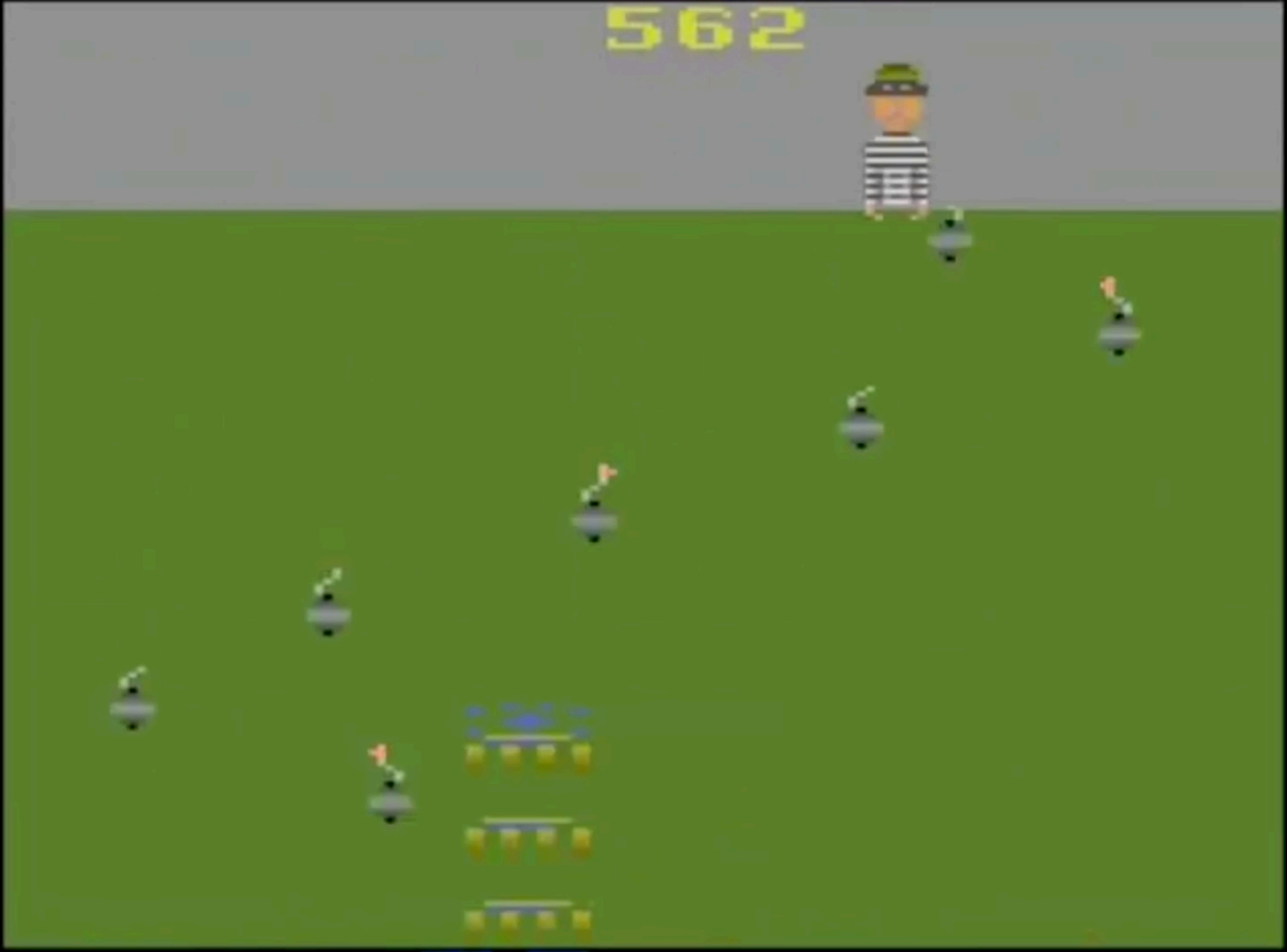
Museo Videojuego Malaga

Atari 2600

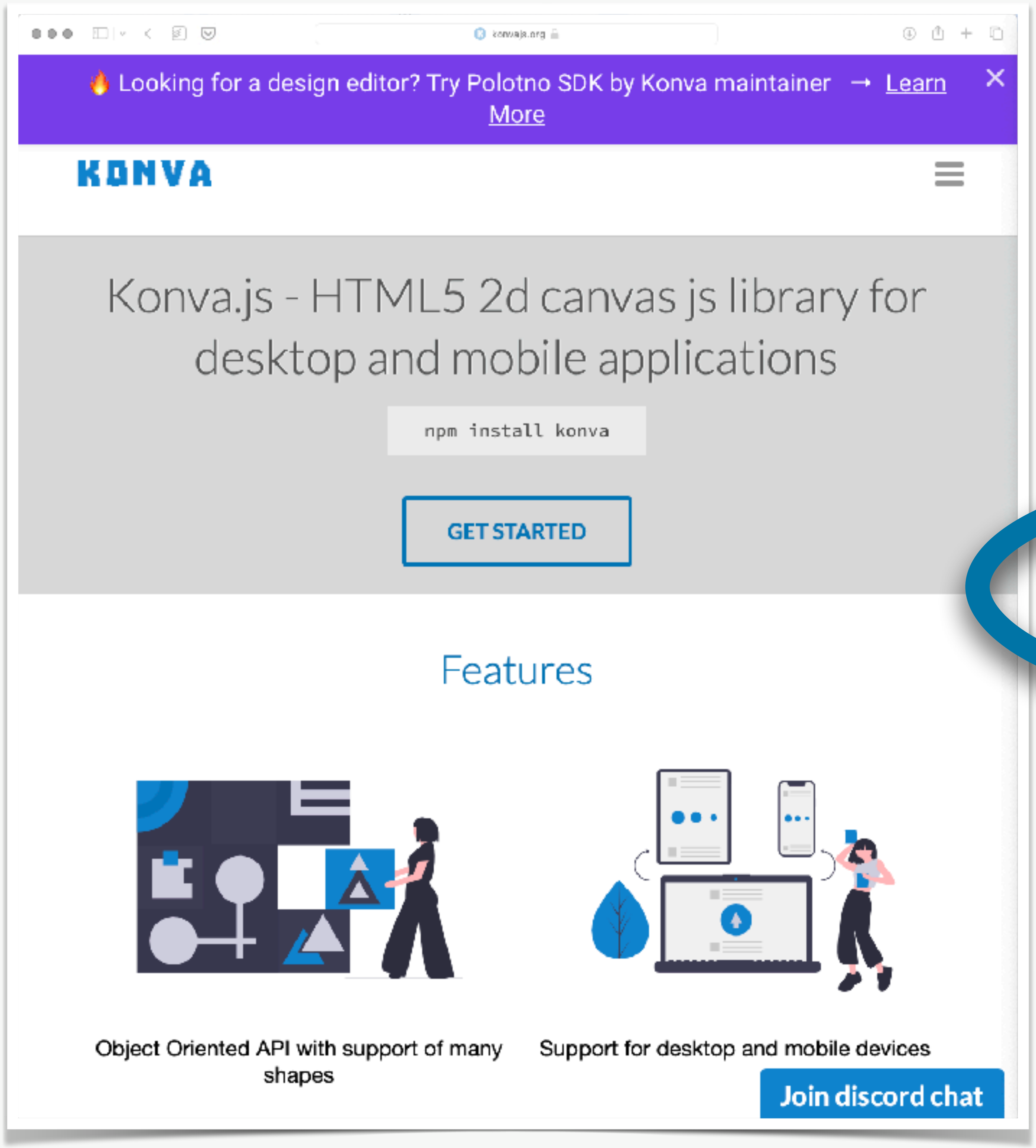
Nintendo


562

Egg drop

Egg drop

React + Konva



🔥 Looking for a design editor? Try Polotno SDK by Konva maintainer → Learn More

KONVA

Konva.js - HTML5 2d canvas js library for desktop and mobile applications

```
npm install konva
```

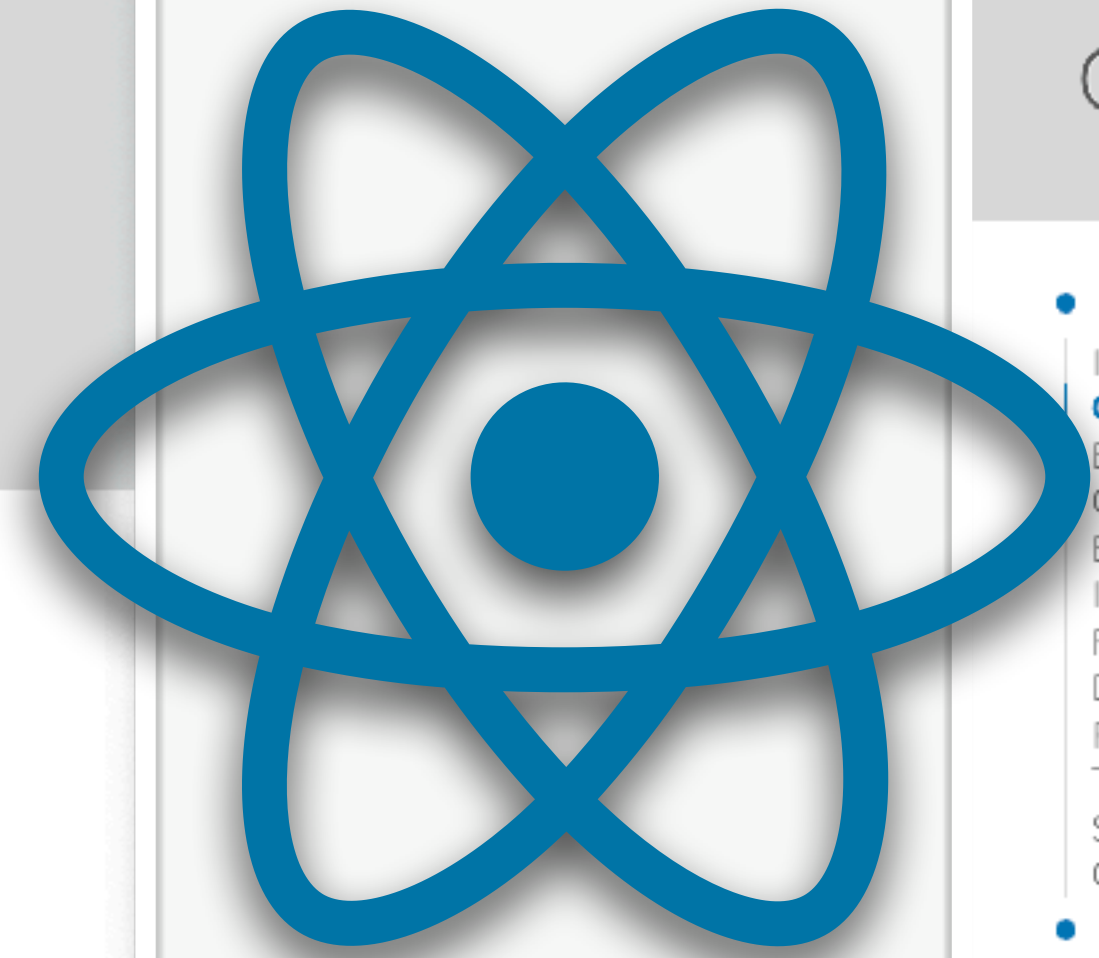
GET STARTED

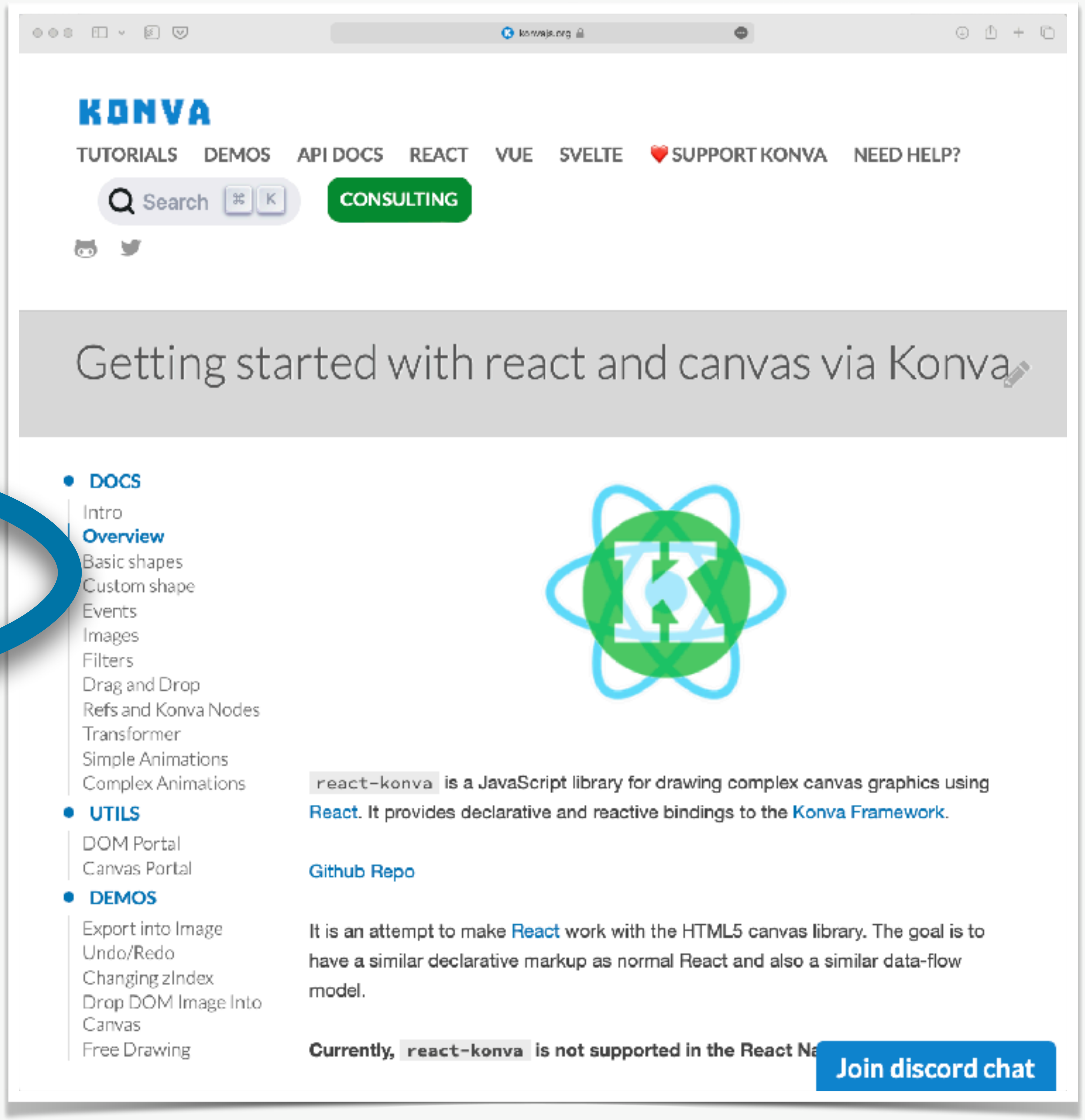
Features

Object Oriented API with support of many shapes

Support for desktop and mobile devices

Join discord chat





KONVA

TUTORIALS DEMOS API DOCS REACT VUE SVELTE ❤️SUPPORT KONVA NEED HELP?

Search ⌘ K CONSULTING

Getting started with react and canvas via Konva

- DOCS
  - Intro
  - Overview
  - Basic shapes
  - Custom shape
  - Events
  - Images
  - Filters
  - Drag and Drop
  - Refs and Konva Nodes
  - Transformer
  - Simple Animations
  - Complex Animations
- UTILS
  - DOM Portal
  - Canvas Portal
- DEMOS
  - Export into Image
  - Undo/Redo
  - Changing zIndex
  - Drop DOM Image Into Canvas
  - Free Drawing

`react-konva` is a JavaScript library for drawing complex canvas graphics using React. It provides declarative and reactive bindings to the Konva Framework.

Github Repo

It is an attempt to make React work with the HTML5 canvas library. The goal is to have a similar declarative markup as normal React and also a similar data-flow model.

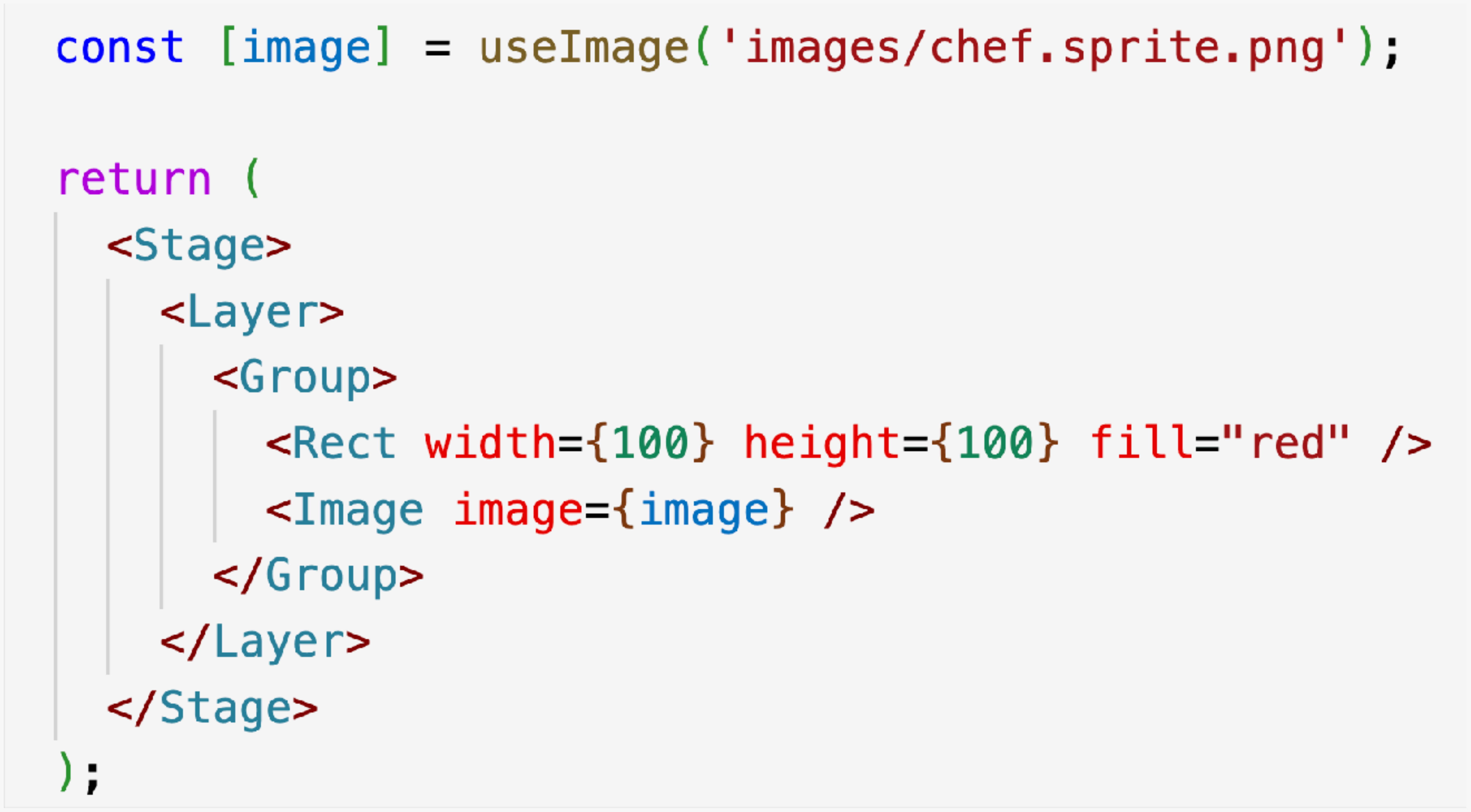
Currently, `react-konva` **is not supported in the React Na**

Join discord chat

Konva

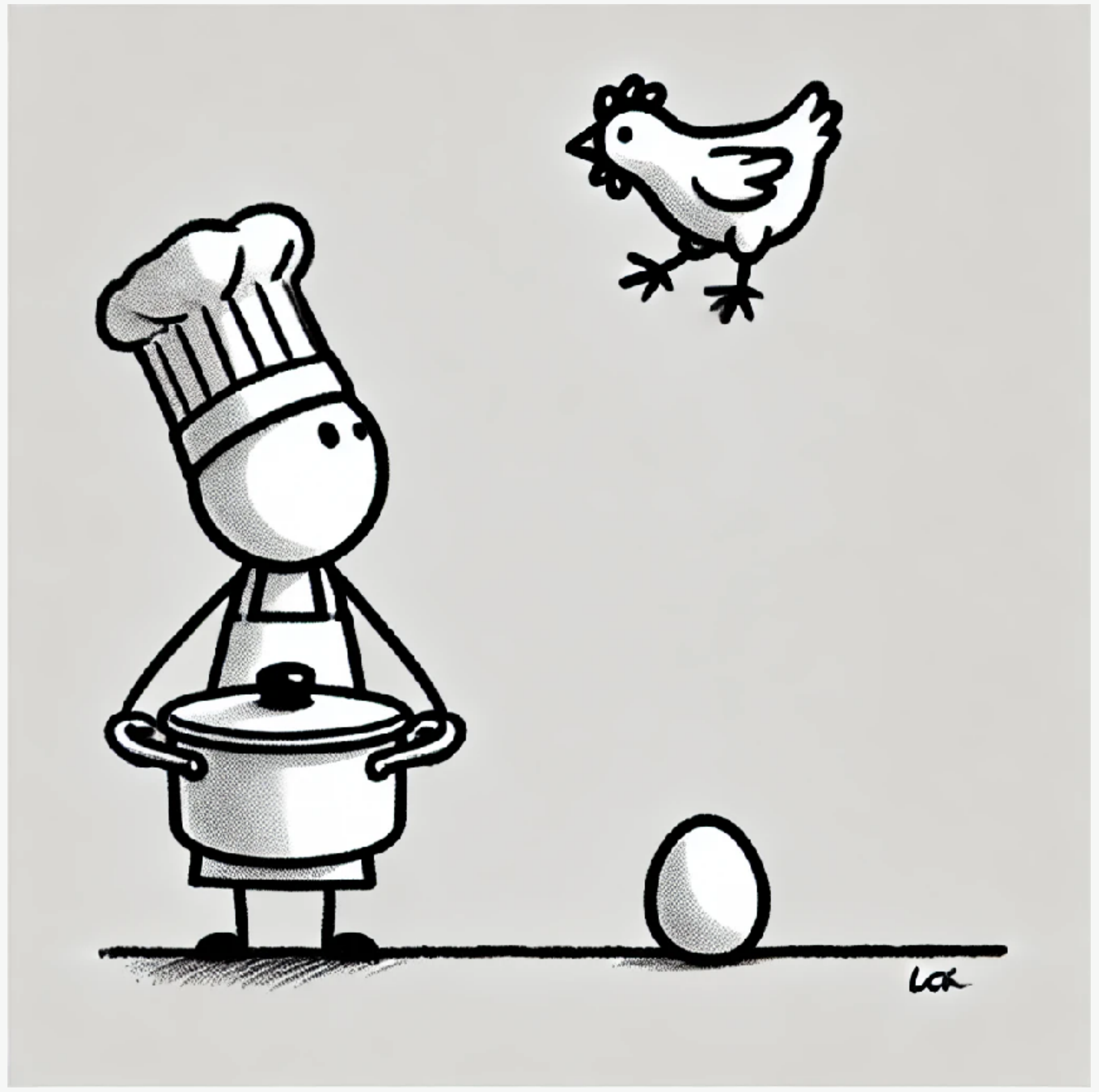
```
return (
  <Stage>
    <Layer listening={false}></Layer>
    <Layer></Layer>
    <Layer></Layer>
  </Stage>
);
```

Konva



```
const [image] = useImage('images/chef.sprite.png');

return (
  <Stage>
    <Layer>
      <Group>
        <Rect width={100} height={100} fill="red" />
        <Image image={image} />
      </Group>
    </Layer>
  </Stage>
);
```

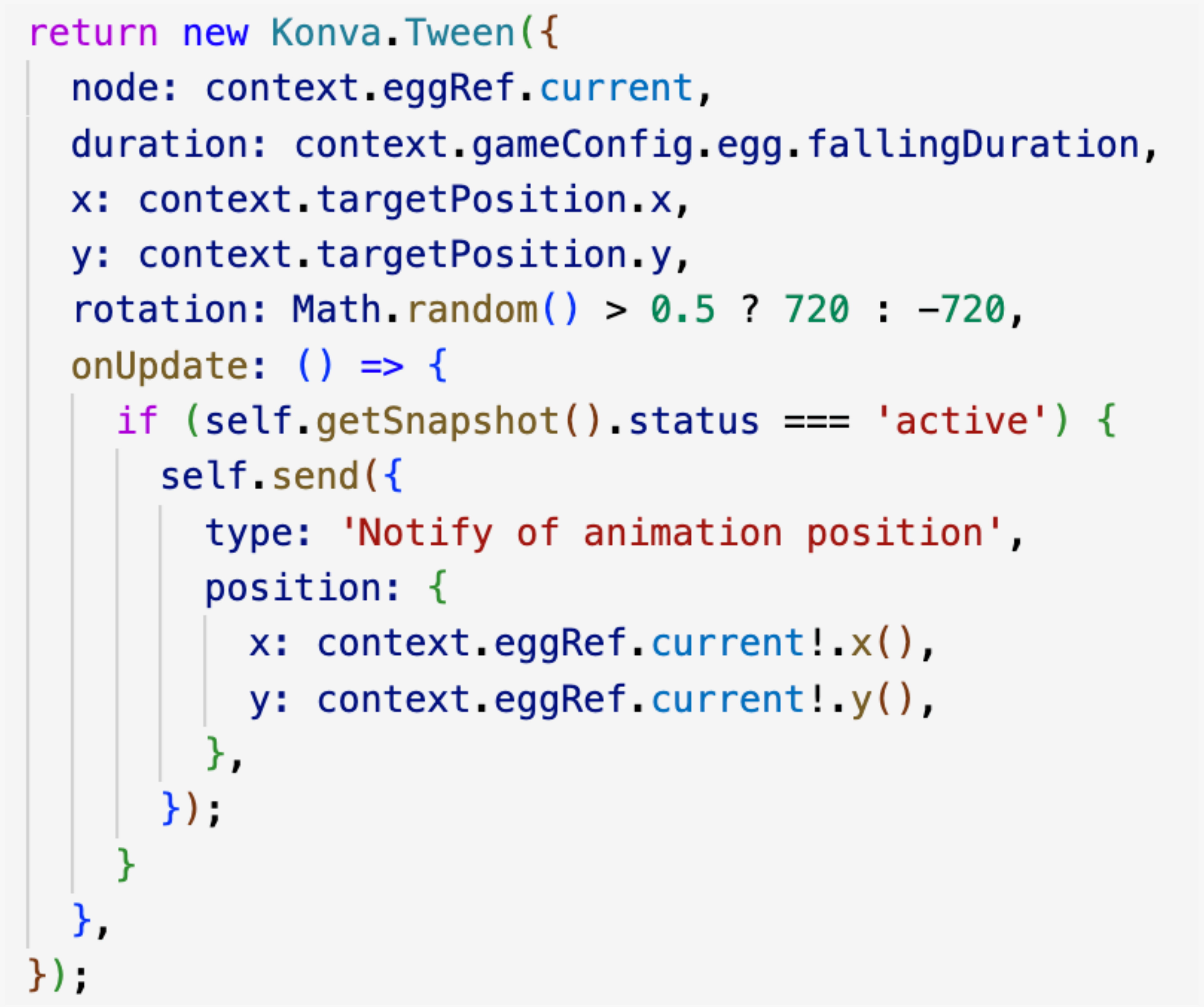
Game Mechanics



- Who are the characters?
- How will they move?
- How will they interact?
- How will the player interact with the game?

First Prototypes

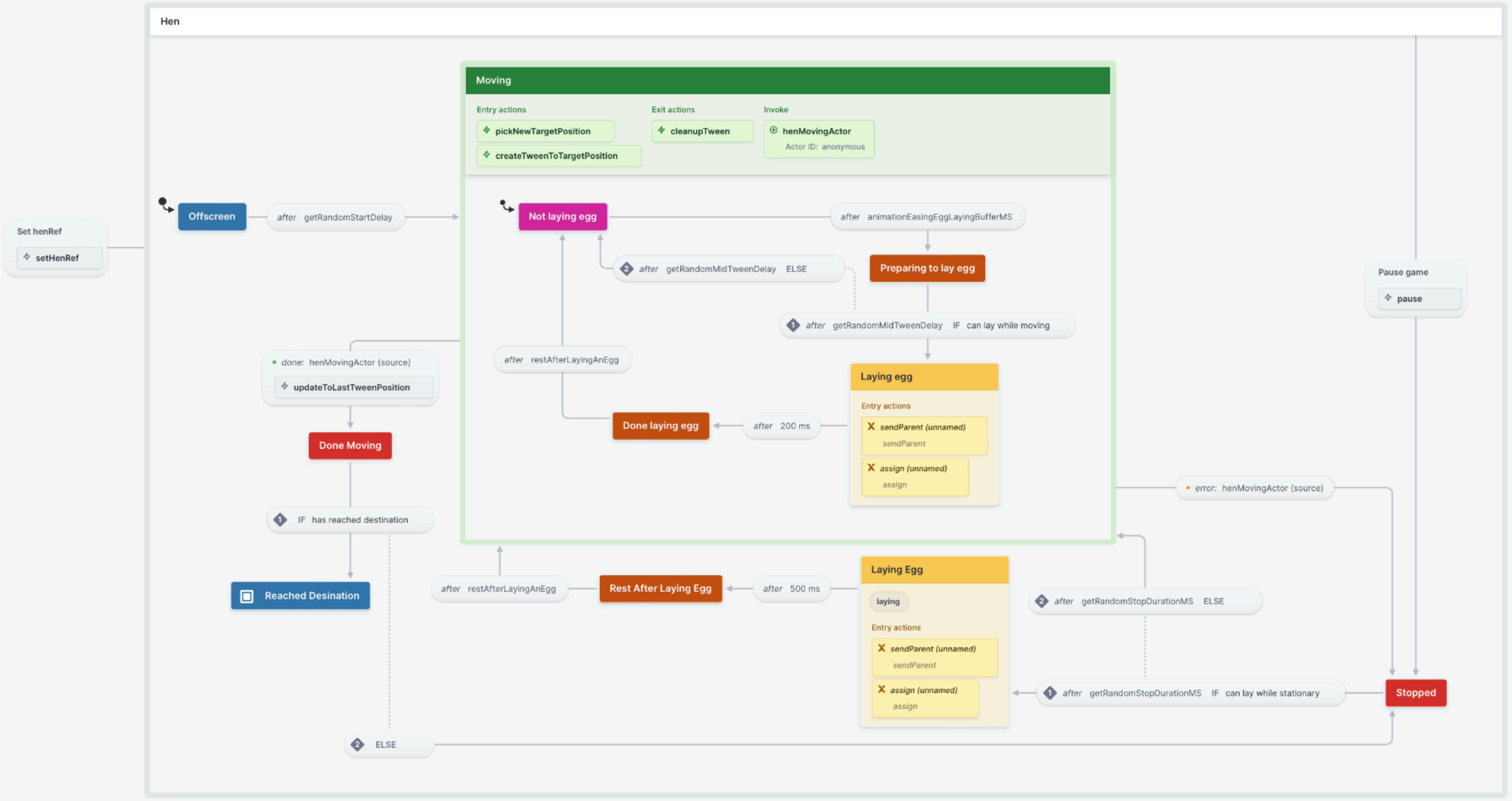
Konva Tween



```
return new Konva.Tween({
  node: context.eggRef.current,
  duration: context.gameConfig.egg.fallingDuration,
  x: context.targetPosition.x,
  y: context.targetPosition.y,
  rotation: Math.random() > 0.5 ? 720 : -720,
  onUpdate: () => {
    if (self.getSnapshot().status === 'active') {
      self.send({
        type: 'Notify of animation position',
        position: {
          x: context.eggRef.current!.x(),
          y: context.eggRef.current!.y(),
        },
      });
    }
  },
});
```

Konva Hit Detection

- **Pixel-level** - User clicks, can include color detection
- **Bounding Box** - Fast, less-precise
- **Shape-level** - Basic shapes like rectangles, circles, polygons
- **Custom Hit Detection** - Irregular or dynamic shapes
- **Group** - Detects hits on any grouped objects <Group>...</Group>


Hen
Set henRef
setHenRef
Offscreen
after getRandomStartDelay
Moving
Entry actions
pickNewTargetPosition
createTweenToTargetPosition
Exit actions
cleanupTween
Invoke
henMovingActor
Actor ID: anonymous
Not laying egg
after animationEasingEggLayingBufferMS
Preparing to lay egg
after getRandomMidTweenDelay ELSE
after getRandomMidTweenDelay IF can lay while moving
after restAfterLayingAnEgg
Laying egg
Entry actions
sendParent (unnamed)
sendParent
assign (unnamed)
assign
Done laying egg
after 200 ms
done: henMovingActor (source)
updateToLastTweenPosition
Done Moving
IF has reached destination
Reached Desination
ELSE
error: henMovingActor (source)
Pause game
pause
Stopped
Laying Egg
laying
Entry actions
sendParent (unnamed)
sendParent
assign (unnamed)
assign
after 500 ms
Rest After Laying Egg
after restAfterLayingAnEgg
after getRandomStopDurationMS ELSE
after getRandomStopDurationMS IF can lay while stationary

stately.ai
My Projects
Egg Drop
Public
Machines
New machine
Chef
Egg
Egg Drop Game
GameLevel
Hen
eggdrop
main
Egg Drop / Chef
Share
Simulate
Deploy
Code
Sources
Structure
Details
Events
Context
Tests
Set chefRef
setChefRef
Chef
Reset isCatchingEgg
resetIsCatchingEgg
Moving
Invoke
movingChefBackAndForthActor
Actor ID: anonymous
Catch
setIsCatchingEgg
playCatchReaction
scheduleResetIsCatchingEgg
done: movingChefBackAndForthActor (source)
updateChefPosition
Set direction
setDirectionProps
Current version
Public
100%

stately.ai
Egg
Pause game
pause
Egg
Idle
Set eggRef
setEggRef
Falling
falling
Init Falling
IF isHenMoving
At an Angle
Invoke
movingFallingActor
Actor ID: anonymous
ELSE
Straight Down
Entry actions
setNewTargetPosition
assign (unnamed)
Invoke
staticFallingActor
Actor ID: anonymous
done: staticFallingActor (source)
setPositionToAnimationEndPosition
done: movingFallingActor (source)
setPositionToAnimationEndPosition
Done Falling
onDone
Landed
IF eggCanHatch
hatchOnFloor
playHatchSound
ELSE
splatOnFloor
playSplatSound
Splatting
Entry actions
setResultStatus
after 1000 ms
Hatching
Entry actions
playHatchingChickSound
Jumping Up
Invoke
hatchingAnimation
Actor ID: anonymous
done: hatchingAnimation (source)
Bouncing Down
Invoke
hatchingAnimation
Actor ID: anonymous
done: hatchingAnimation (source)
Animation Done
onDone
Hatched
Entry actions
setResultStatus
after 500 ms
Exiting
chick
Entry actions
setTargetPositionToExit
Invoke
chickExitingStageActor
Actor ID: anonymous
done: chickExitingStageActor (source)
Notify of animation position IF isEggOffScreen
setResultStatus
Catch
setResultStatus
Notify of animation position ELSE IF isEggNearChefPo
notifyParentOfPosition
Done

XSTATE

XSTATE

```
const eggState = useSelector(eggActorRef, (state) => state);
```

Sorry, bad yolk!

Kitchen bg
Gen: 1 Time: 0 seconds

Gen: 0 Time: 2 seconds

Vector Graphics

Vector Graphics?

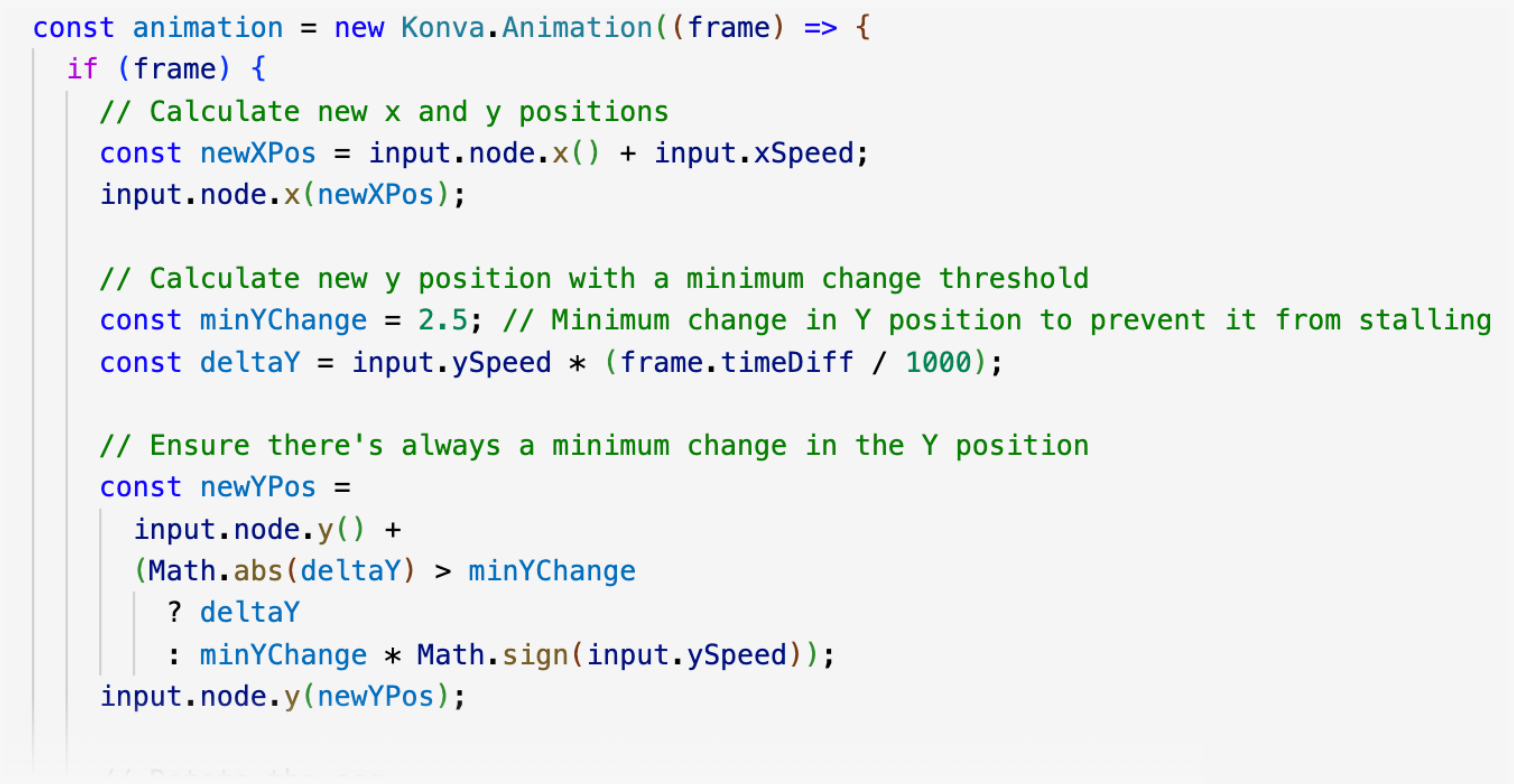
OpenAI

[redacted] [redacted]

Kitche

Gen: 1 Time: 49 seconds

Konva Animation



```
const animation = new Konva.Animation((frame) => {
  if (frame) {
    // Calculate new x and y positions
    const newXPos = input.node.x() + input.xSpeed;
    input.node.x(newXPos);

    // Calculate new y position with a minimum change threshold
    const minYChange = 2.5; // Minimum change in Y position to prevent it from stalling
    const deltaY = input.ySpeed * (frame.timeDiff / 1000);

    // Ensure there's always a minimum change in the Y position
    const newYPos =
      input.node.y() +
      (Math.abs(deltaY) > minYChange
        ? deltaY
        : minYChange * Math.sign(input.ySpeed));
    input.node.y(newYPos);
```

In between levels

Kitche

Total eggs laid 57

Total eggs caught 14

Catch rate 25%

[redacted] [redacted] [redacted] [redacted] [redacted] K [redacted]

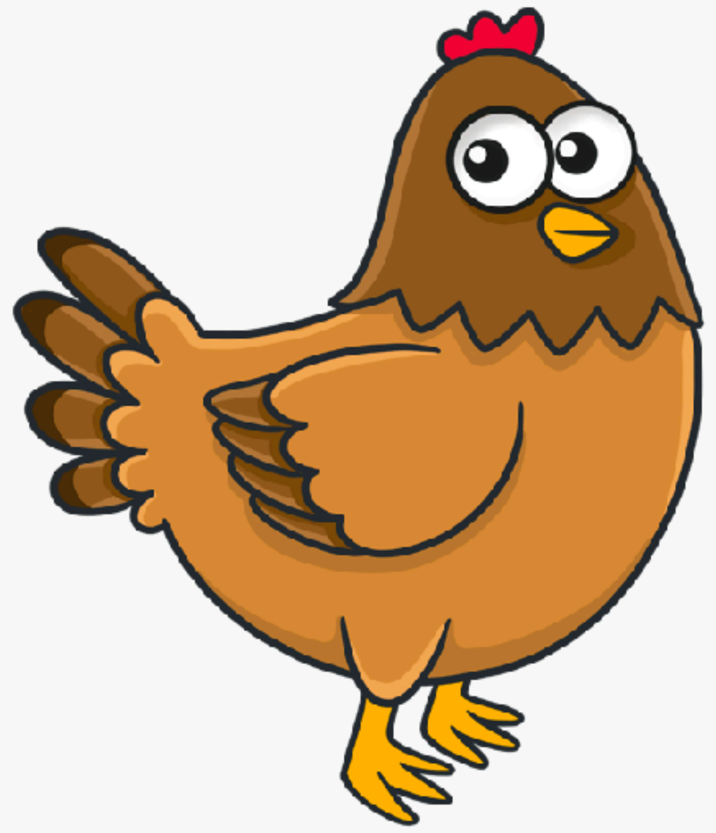
Gen: 0 Time: 16 seconds

Score: 0

Eggs: 0

Gold: 0

Open AI Casting Call for Hens



SYNIUM SOFTWARE

Egg Drop Main Board (Edited)

Text
Shape
Line
Path
VectorAI
LiveShape
Clipart
Lens Flare
Templates
Image
Background
Group
Instance
Embed
Inspector
Shared Styles
Style Presets
Hen Larger
Snapping
Grid
Labels
Render Mode
Full
Zoom
353.5 %
Sort by References

Egg Glow
Chick
Egg Broken
Title Page
Hen Larger
forward 17 Objects
angle-left 15 Objects
angle-right 15 Objects
walk-left-1 12 Objects
walk-left-2 12 Objects
walk-left-3 12 Objects
walk-left-4 12 Objects
walk-right-1 12 Objects
walk-right-2 12 Objects
walk-right-3 12 Objects
walk-right-4 12 Objects
back-left 6 Objects
back-right 6 Objects
jump-1 14 Objects
jump-2 12 Objects
Logo Large
Logo Square
Favicon
Points

Please select objects on the artboard to change properties, or select style presets

Colors on this Artboard:

Text
Shape
Line
Path
VectorAI
LiveShape
Clipart
Lens Flare
Templates
Image
Background
Group
Instance
Embed
Inspector
Shared Styles
Style Presets
Hen Larger
Snapping
Grid
Labels
Render Mode
Full
Zoom
353.5 %

Egg Drop Main Board (Edited)

Egg Glow
Chick
Egg Broken
Title Page
Hen Larger
forward 17 Objects
angle-left 15 Objects
angle-right 15 Objects
walk-left-1 12 Objects
walk-left-2 12 Objects
walk-left-3 12 Objects
walk-left-4 12 Objects
walk-right-1 12 Objects
walk-right-2 12 Objects
walk-right-3 12 Objects
walk-right-4 12 Objects
back-left 6 Objects
back-right 6 Objects
jump-1 14 Objects
jump-2 12 Objects
Logo Large
Logo Square
Favicon
Points

Please select objects on the artboard to change properties, or select style presets

Colors on this Artboard:
Sort by References

Text
Shape
Line
Path
VectorAI
LiveShape
Clipart
Lens Flare
Templates
Image
Background
Group
Instance
Embed
Inspector
Shared Styles
Style Presets
Hen Larger
Colors on this Artboard:
Sort by References
Snapping
Grid
Labels

Egg Drop Main Board (Edited)

- Egg Glow
- Chick
- Egg Broken
- Title Page
- Hen Larger
  - forward 7 Objects
  - angle-left 5 Objects
  - angle-right 5 Objects
  - walk-left-1 2 Objects
  - walk-left-2 2 Objects
  - walk-left-3 2 Objects
  - walk-left-4 2 Objects
  - walk-right-1 2 Objects
  - walk-right-2 2 Objects
  - walk-right-3 2 Objects
  - walk-right-4 2 Objects
  - back-left 6 Objects
  - back-right 6 Objects
  - jump-1 4 Objects
  - jump-2 2 Objects
- Logo Large
- Logo Square
- Favicon
- Points

Please select objects on the artboard to change properties, or select style presets

Render Mode Full

Zoom 353.5 %

Egg Drop Main Board
Text
Shape
Line
Path
VectorAI
LiveShape
Clipart
Lens Flare
Templates
Image
Background
Group
Instance
Embed
Egg Glow
Chick
Egg Broken
Title Page
Hen Larger
forward
7 Objects
angle-left
5 Objects
angle-right
5 Objects
walk-left-1
2 Objects
walk-left-2
2 Objects
walk-left-3
2 Objects
walk-left-4
2 Objects
walk-right-1
2 Objects
walk-right-2
2 Objects
walk-right-3
2 Objects
walk-right-4
2 Objects
back-left
6 Objects
back-right
6 Objects
jump-1
4 Objects
jump-2
2 Objects
Logo Large
Logo Square
Favicon
Points
Hen Larger
Inspector
Shared Styles
Style Presets
Colors on this Artboard:
Sort by References
Snapping
Grid
Labels
Please select objects on the artboard to change properties, or select style presets

Render Mode X-ray
Zoom 353.5 %

Texture Packer

hen.sprite.tps
Open project
Save project
Add sprites
Remove sprites
Add smart folder
Sprite settings
Preview Anims
Publish sprite sheet
Split sheet
Tutorials
Feedback
Sprites
angle-left.png
angle-right.png
back-left.png
back-right.png
forward.png
jump-1.png
jump-2.png
walk-left-1.png
walk-left-2.png
walk-left-3.png
walk-left-4.png
walk-right-1.png
walk-right-2.png
walk-right-3.png
walk-right-4.png
Animation preview
Speed
7 FPS
4x
Use texture format PNG-8 to r
Use PNG-8 format
Advanced settings >>
Zoom:
80 %
1:1
Fit
Auto Fit
Display outlines
456x760 (RAM: 1353kB)

Settings

Output files

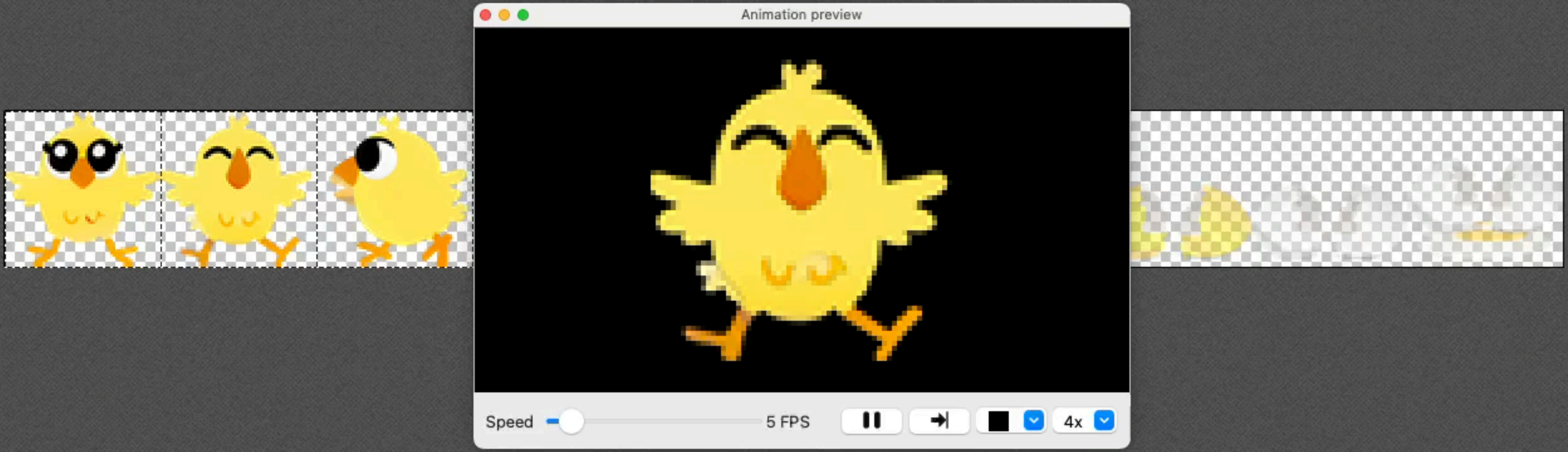
Framework: JSON (Hash)
Data file: ation/Hen, Egg, Chick/hen.sprite.
Texture file: hen.sprite.png

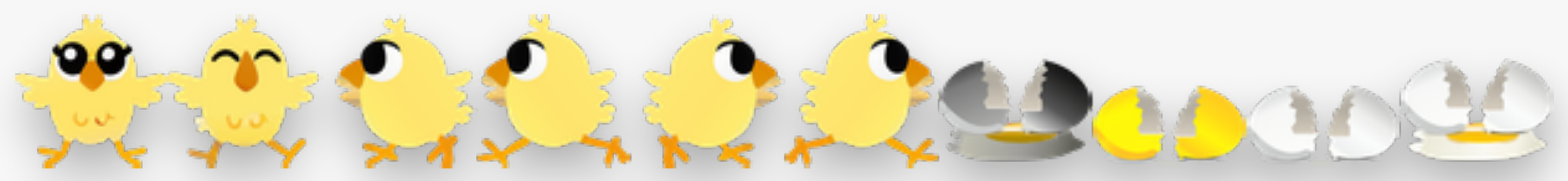
Image format

Texture format: PNG-32
Pixel format: RGBA8888
Scaling variants:

Packing

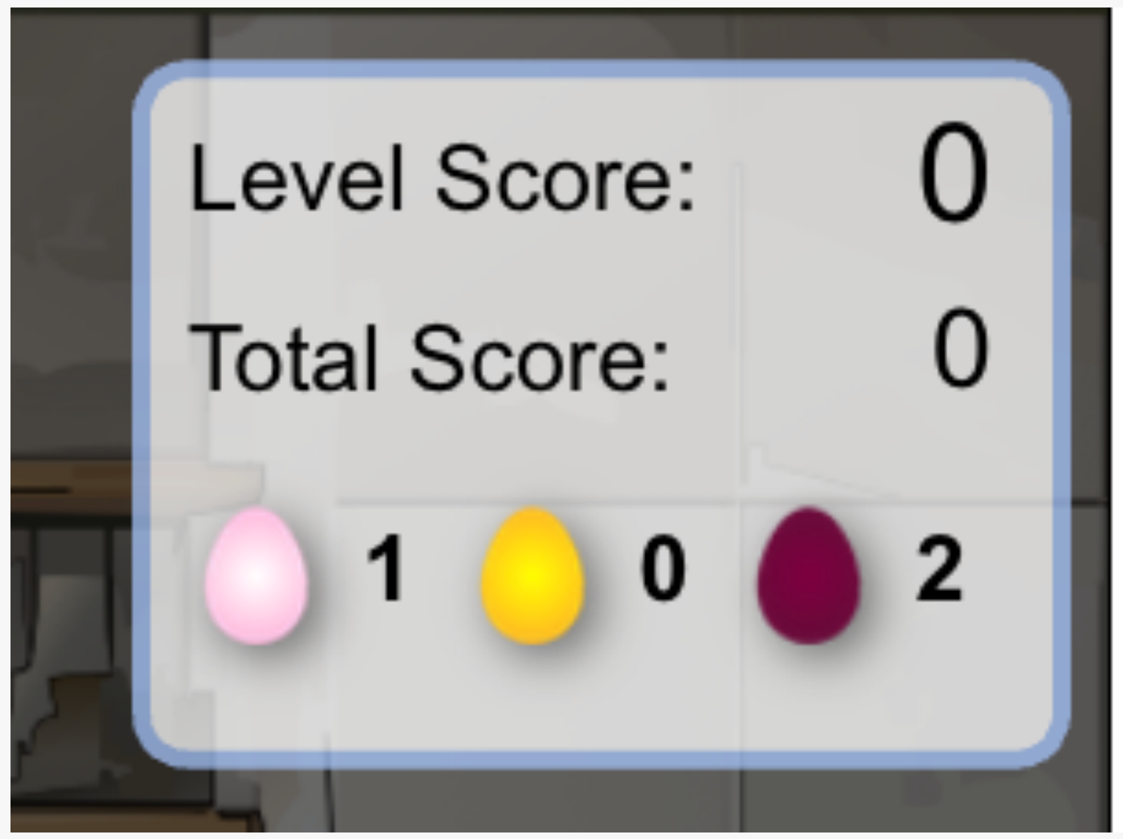
Algorithm: MaxRects
Max size: 2048
Trim mode: None
Multi pack: Off
Extrude: 1

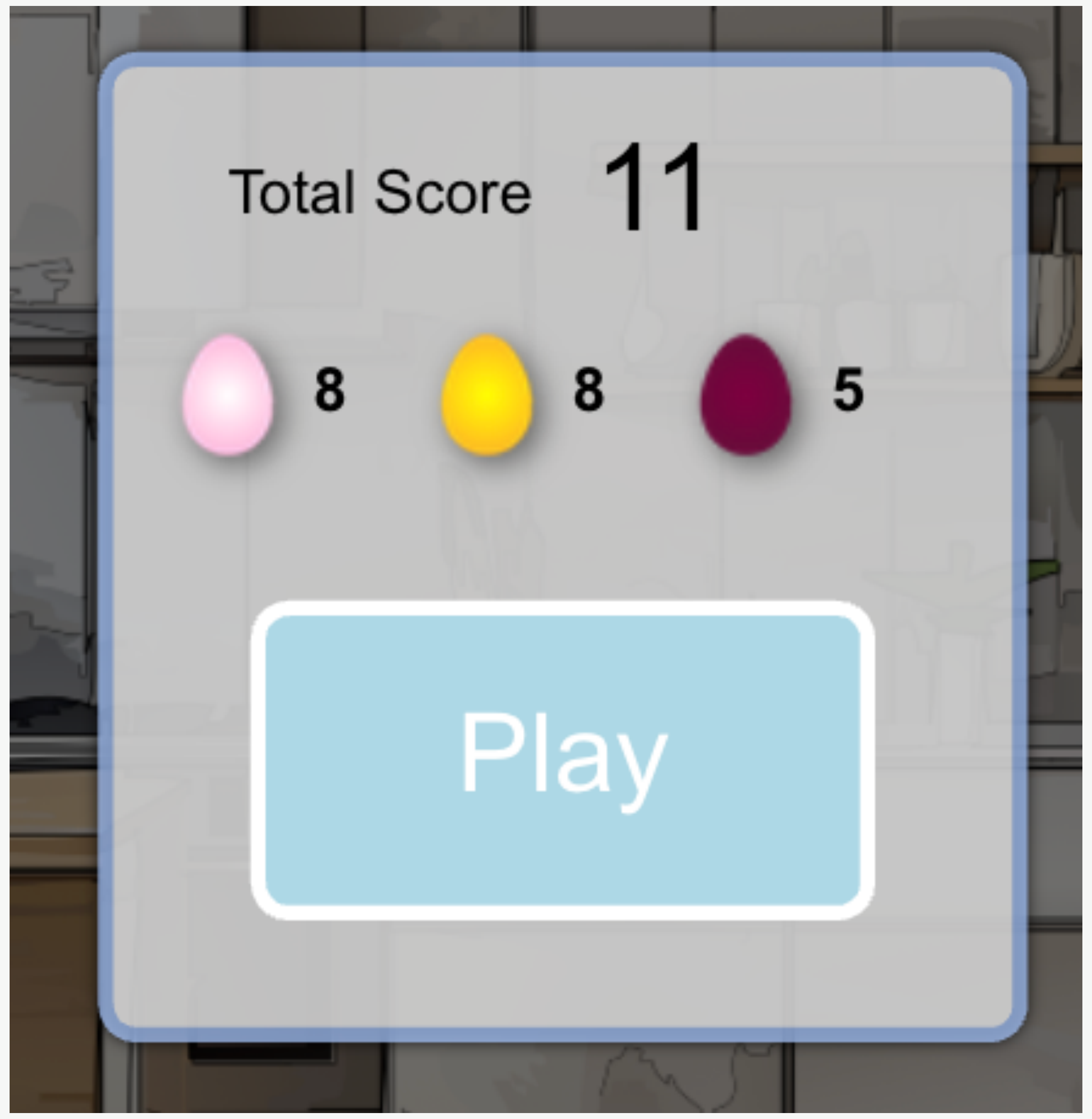

Animation preview
Speed
5 FPS
4x



What about fonts?

Arial in a game is so sad





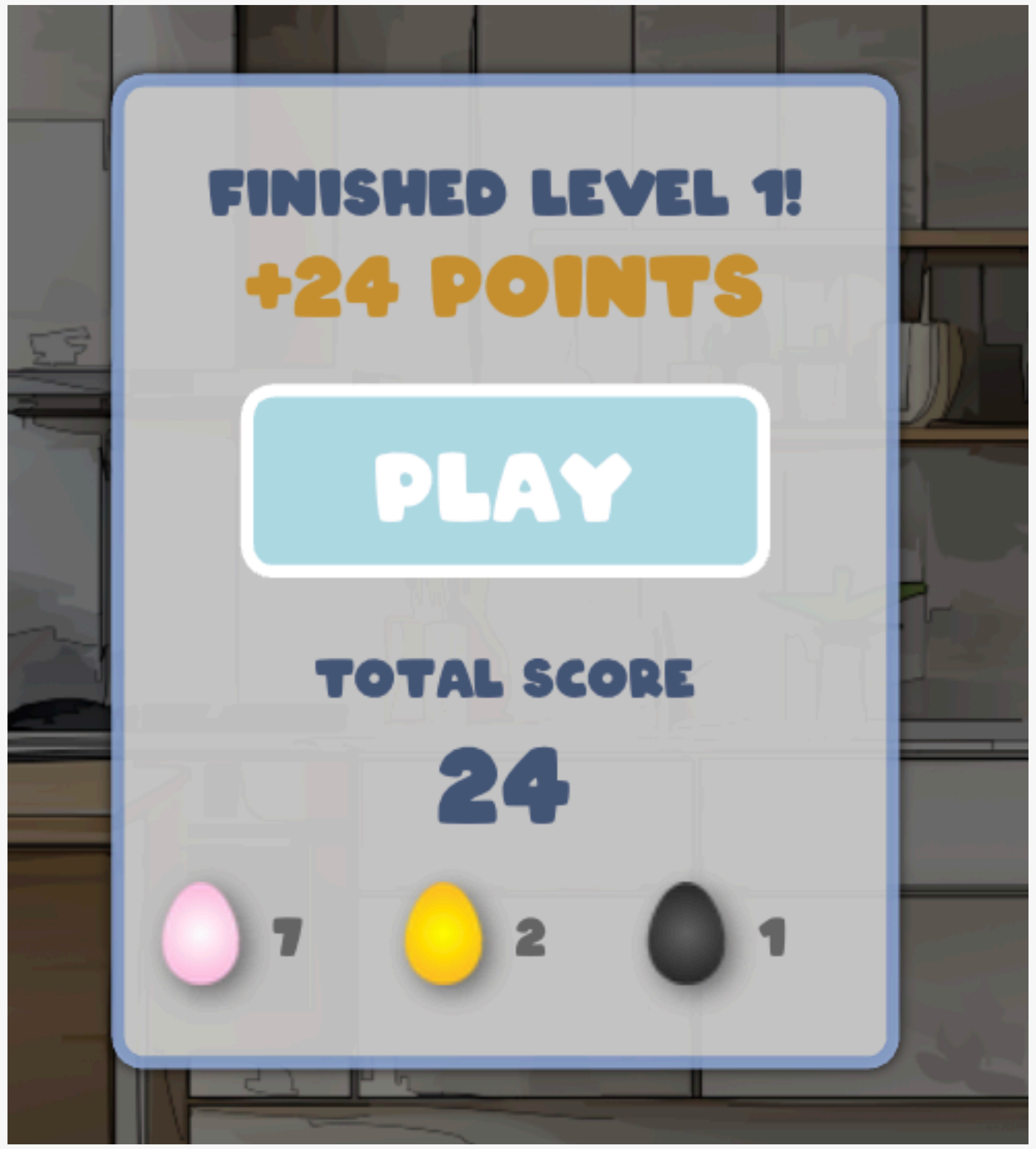
ARCO

THE QUICK YELLOW CHICK JUMPS OVER THE LAZY CHEF.

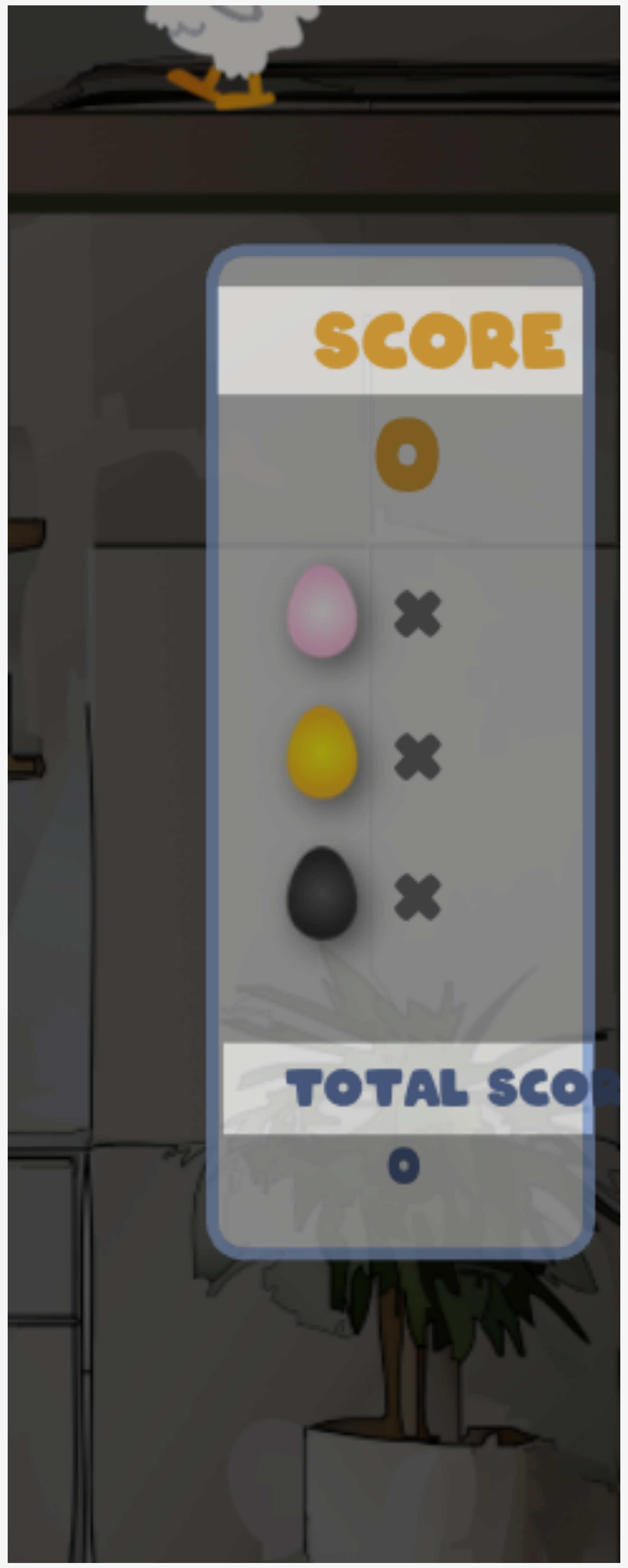
```css
@font-face {
  font-family: 'Arco';
  src: local('Arco-Regular'), url('/fonts/ARCO.ttf') format('truetype');
}
```

ARCO

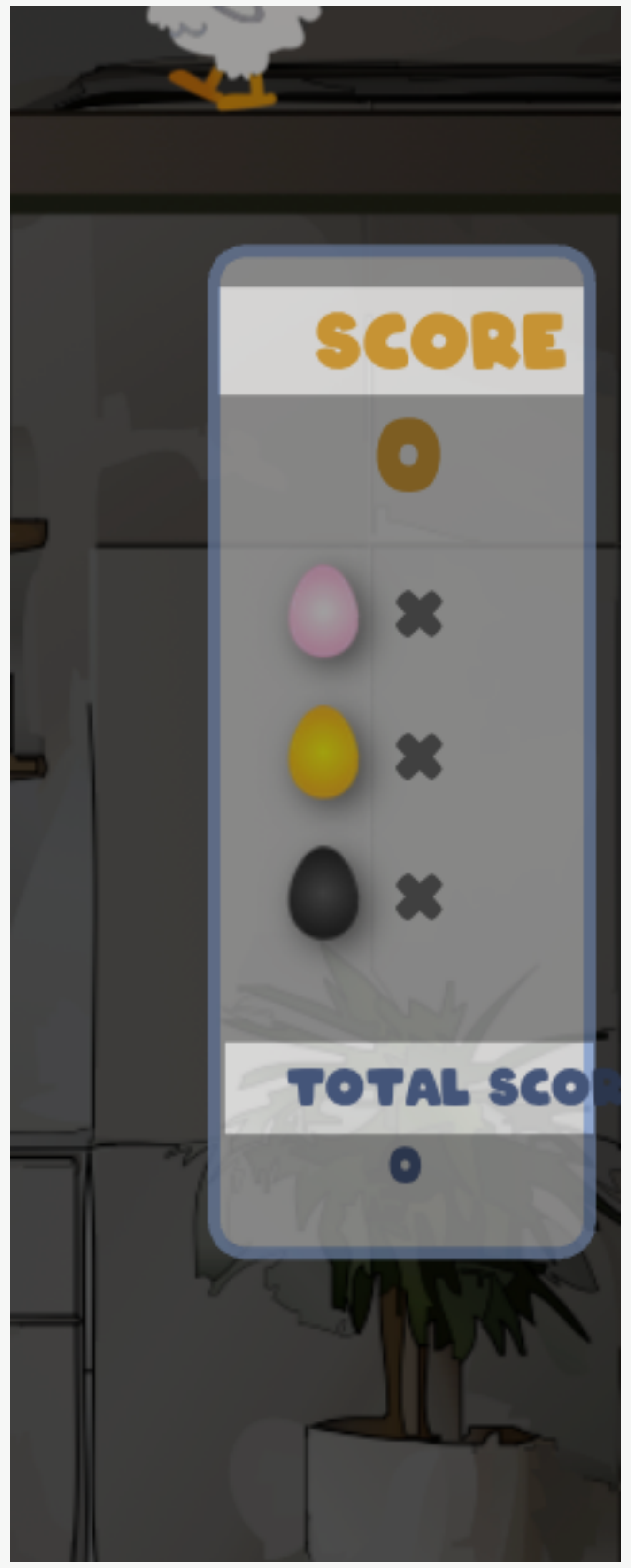
THE QUICK YELLOW CHICK JUMPS OVER THE LAZY CHEF.



ARCO



ARCO



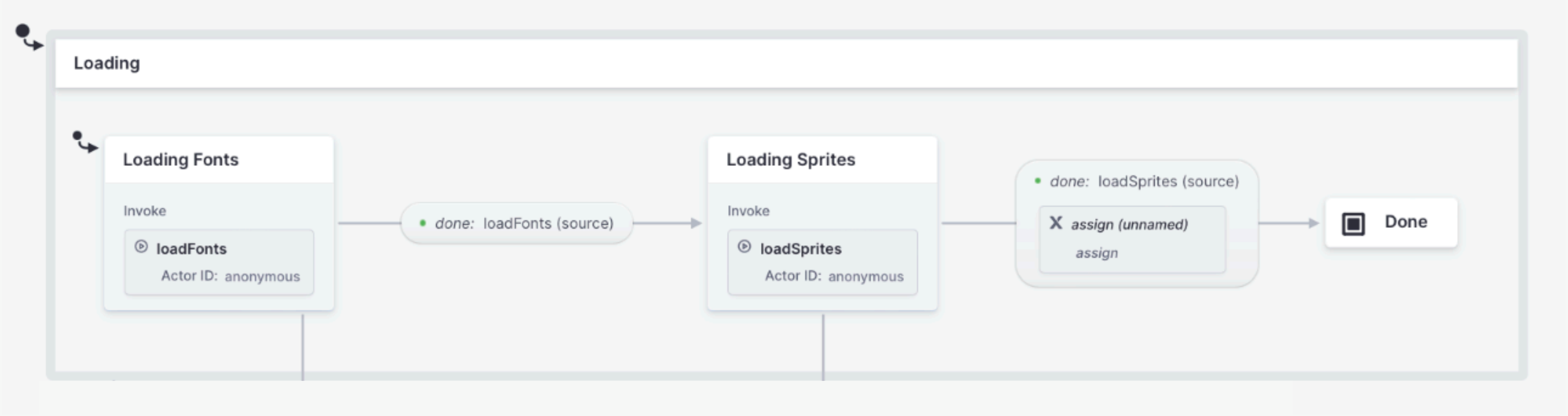
FOUT - *Flash of unstyled text*

FOIT - *Flash of invisible text*

FOFT - *Flash of faux text*

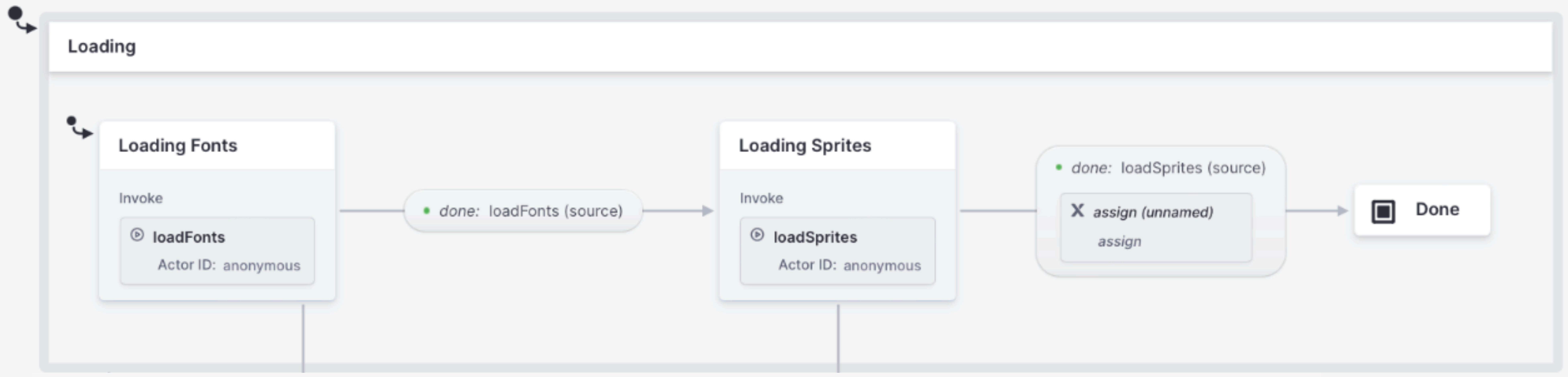
ARCO

SCORE
0
TOTAL SCO
0


Loading
Loading Fonts
Invoke
loadFonts
Actor ID: anonymous
done: loadFonts (source)
Loading Sprites
Invoke
loadSprites
Actor ID: anonymous
done: loadSprites (source)
assign (unnamed)
assign
Done

ARCO

new FontFaceObserver('Arco');

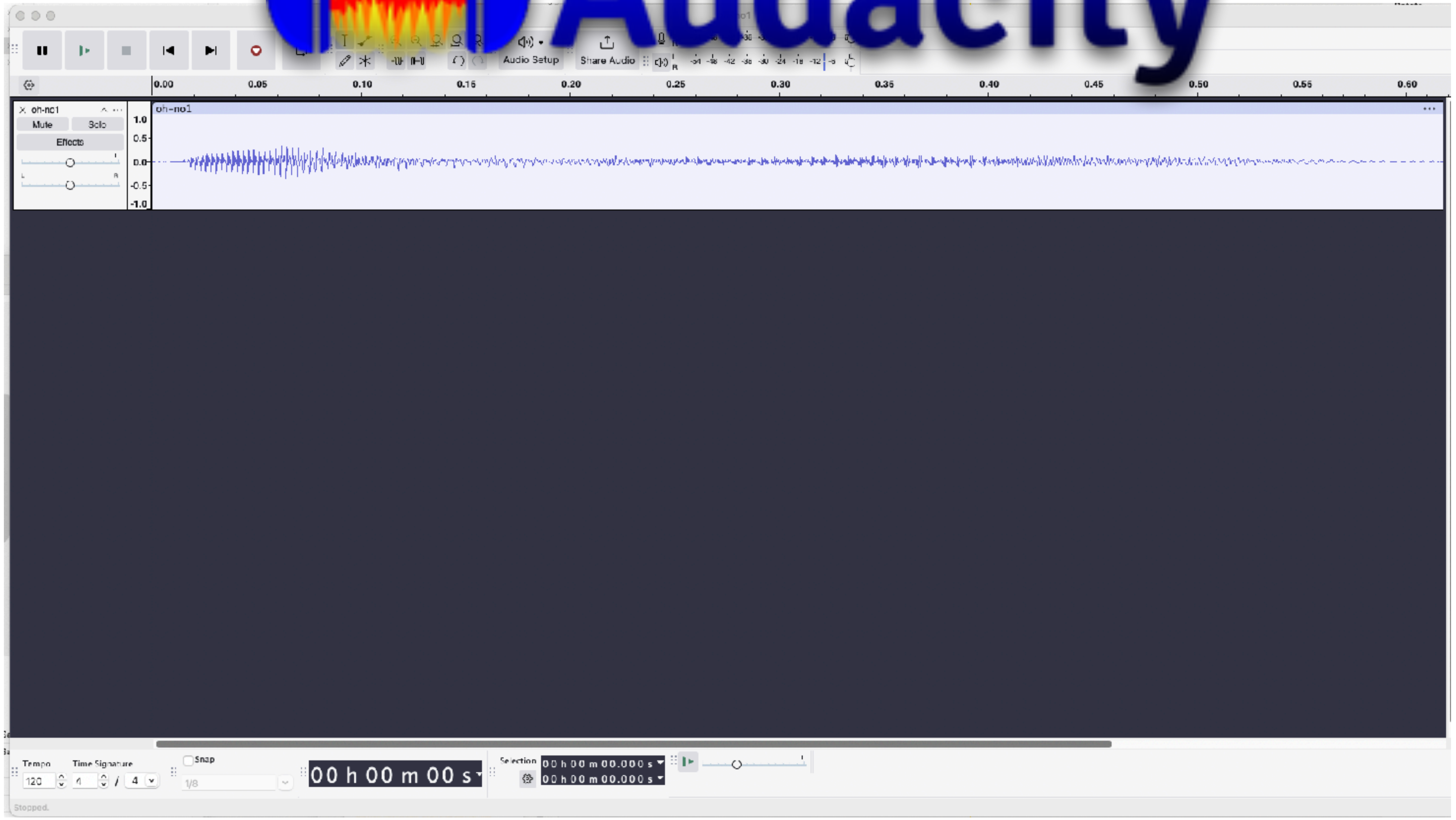


```
loadFonts: fromPromise(() => {
  const arcoFont = new FontFaceObserver('Arco');
  const jetBrainsMonoFont = new FontFaceObserver('JetBrains Mono');
  return Promise.all([arcoFont.load(), jetBrainsMonoFont.load()]);
}),
```

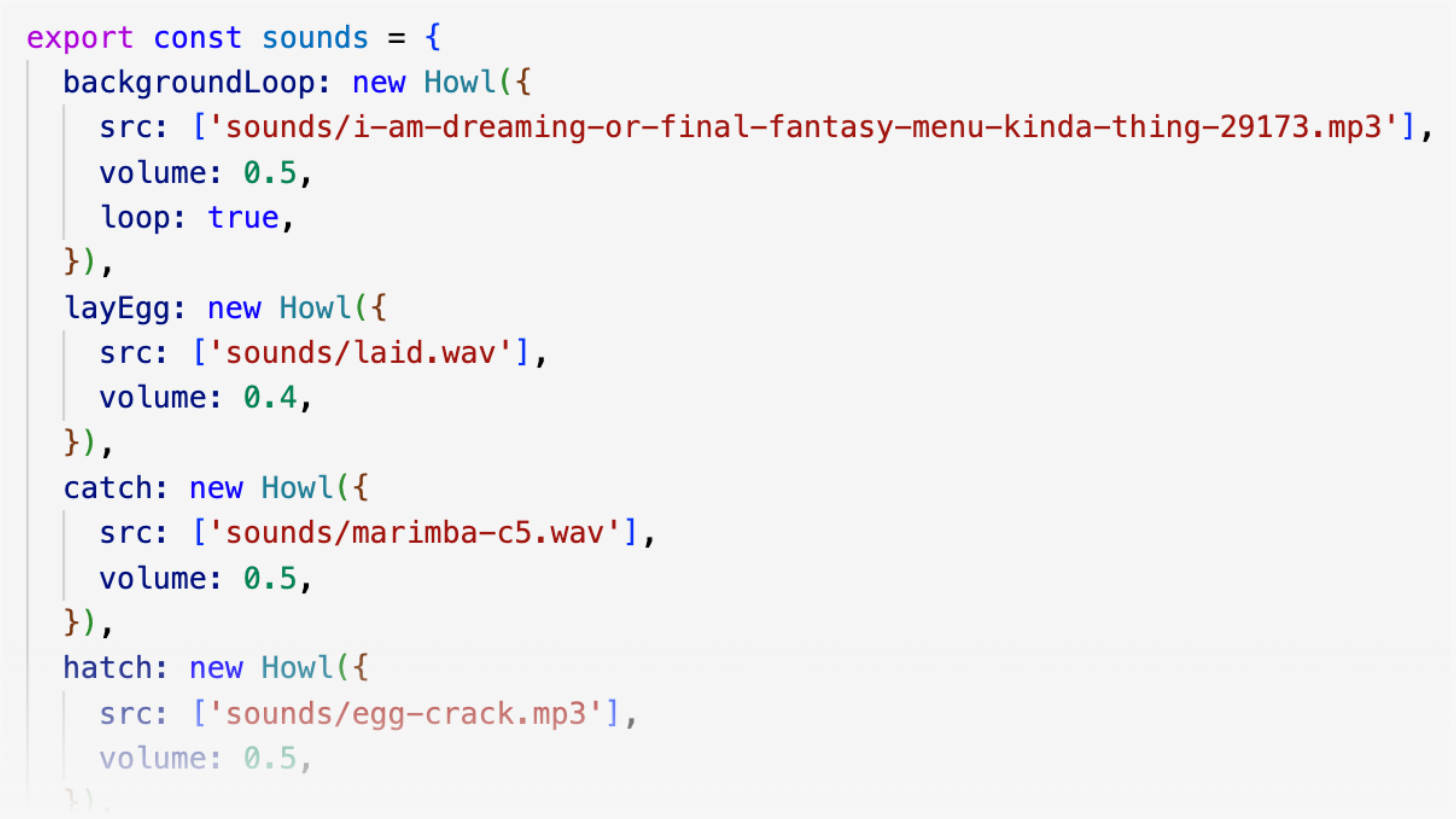
EGG DROP
W'SUP!?

EGG DROP
W'SUP!?

Audacity

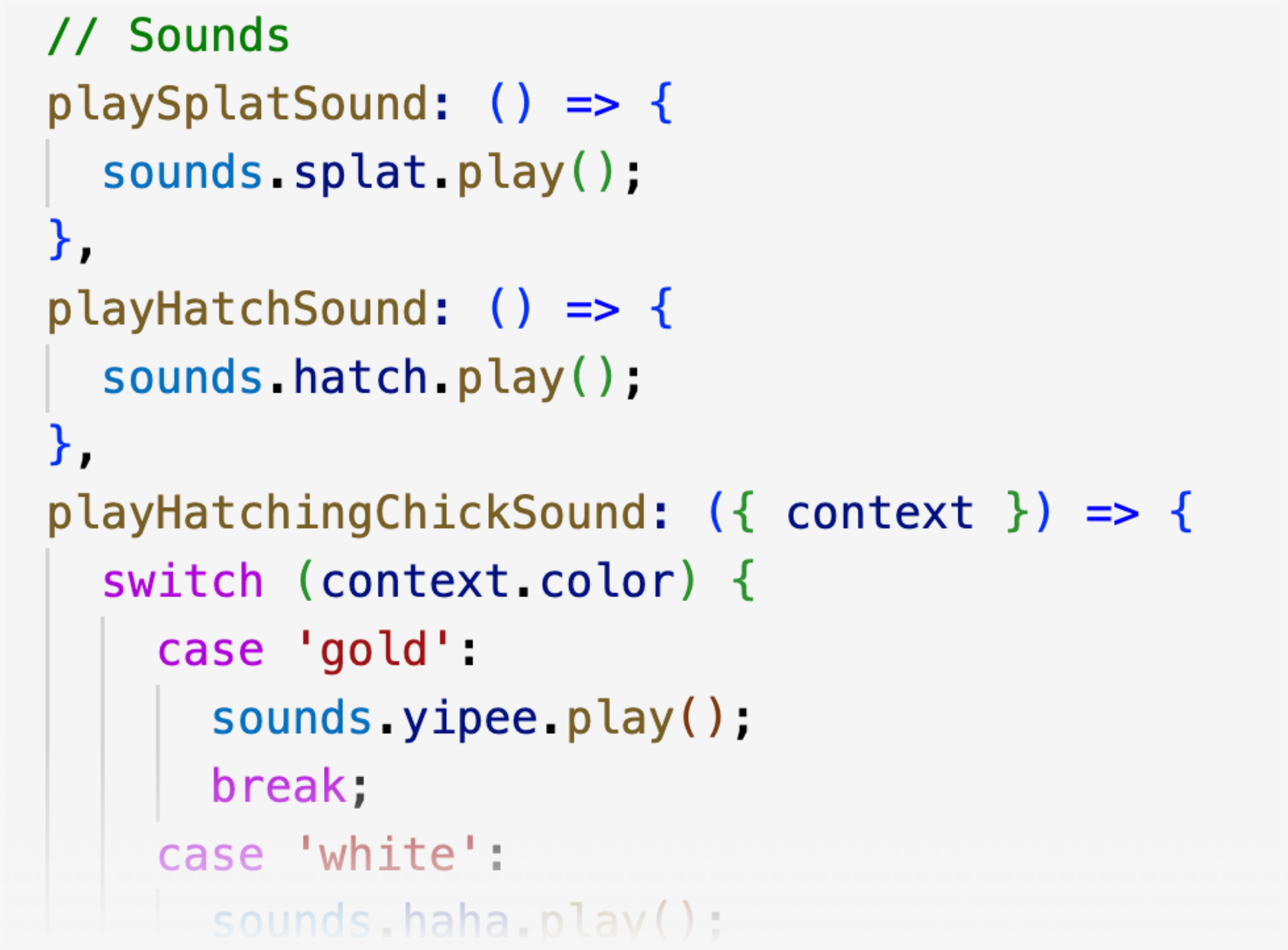

oh-no1
Mute
Solo
Effects
Audio Setup
Share Audio
Tempo
Time Signature
Snap
Selection
00 h 00 m 00 s
Stopped.

HOWLER.JS



```
export const sounds = {
  backgroundLoop: new Howl({
    src: ['sounds/i-am-dreaming-or-final-fantasy-menu-kinda-thing-29173.mp3'],
    volume: 0.5,
    loop: true,
  }),
  layEgg: new Howl({
    src: ['sounds/laid.wav'],
    volume: 0.4,
  }),
  catch: new Howl({
    src: ['sounds/marimba-c5.wav'],
    volume: 0.5,
  }),
  hatch: new Howl({
    src: ['sounds/egg-crack.mp3'],
    volume: 0.5,
  }),
```

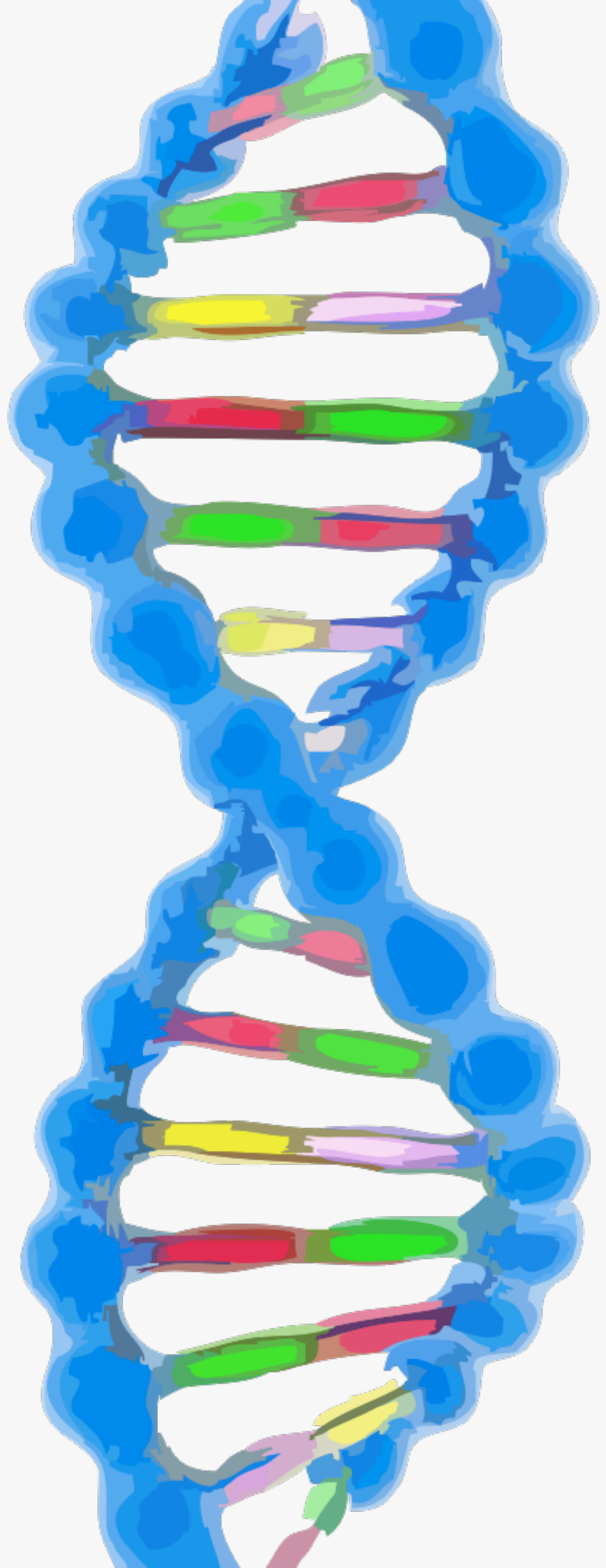
HOWLER.JS + XSTATE



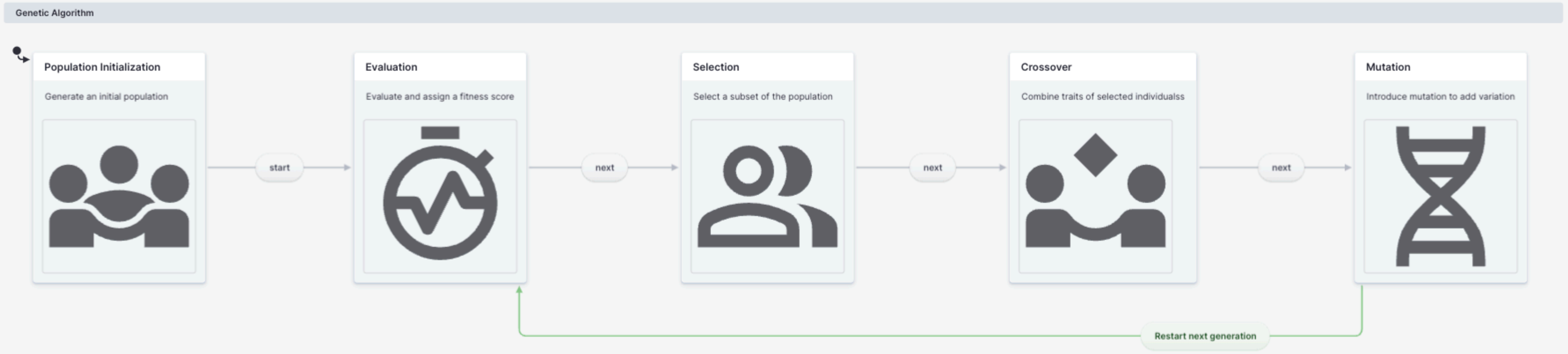
```
// Sounds
playSplatSound: () => {
  sounds.splat.play();
},
playHatchSound: () => {
  sounds.hatch.play();
},
playHatchingChickSound: ({ context }) => {
  switch (context.color) {
    case 'gold':
      sounds.yipee.play();
      break;
    case 'white':
      sounds.haha.play();
```

GENETIC ALGORITHMS

- DESIRED BEHAVIOR
- OPTIMAL DESIGN
- SOLVE COMPLEX SEARCH PROBLEMS



States of a genetic algorithm


Genetic Algorithm
Population Initialization
Generate an initial population
start
Evaluation
Evaluate and assign a fitness score
next
Selection
Select a subset of the population
next
Crossover
Combine traits of selected individualss
next
Mutation
Introduce mutation to add variation
Restart next generation

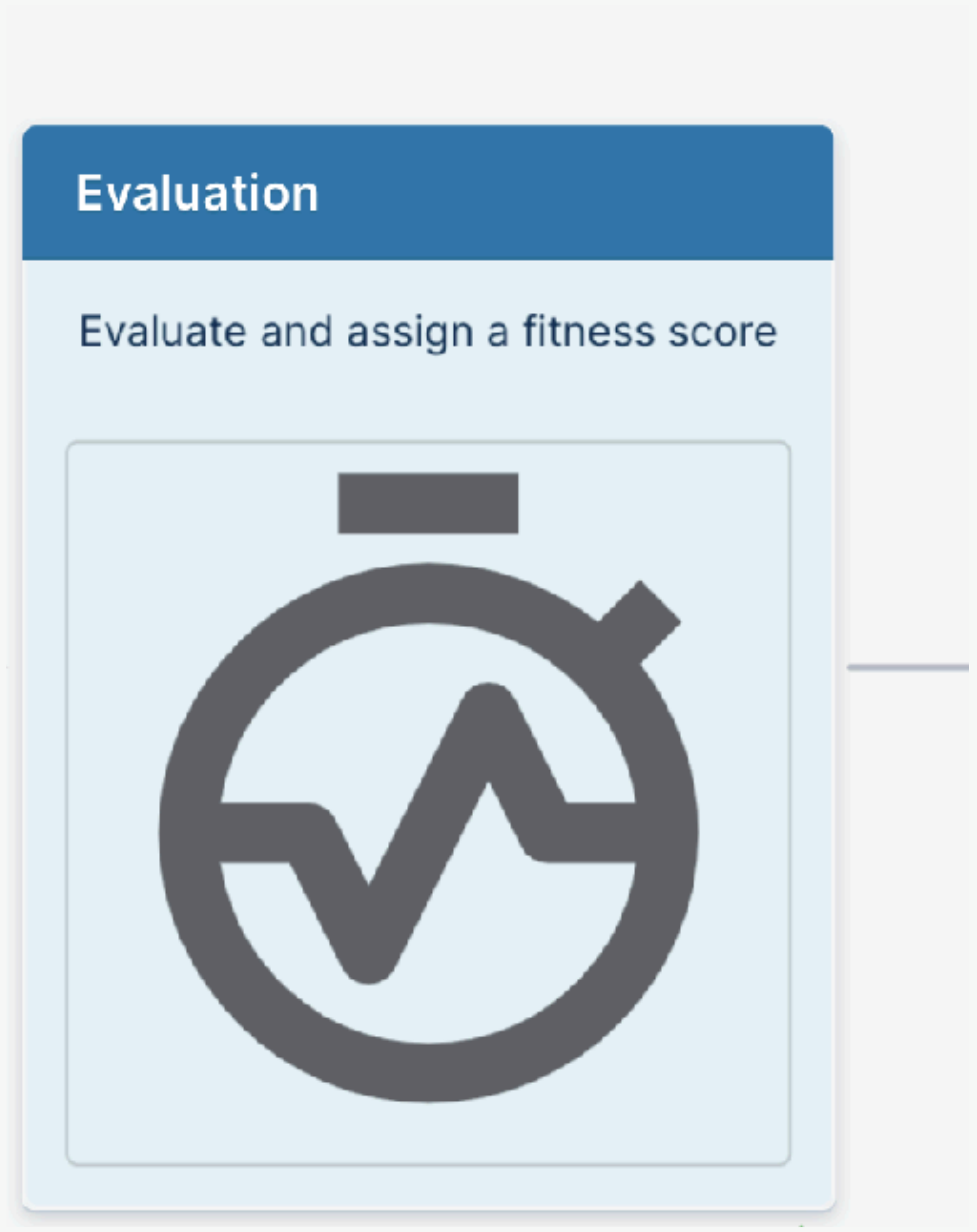
Population Initialization

Population Initialization

Generate an initial population

- Many “individuals”
- Each with a potential solution
- Stored in their “DNA”

Evaluation & Fitness



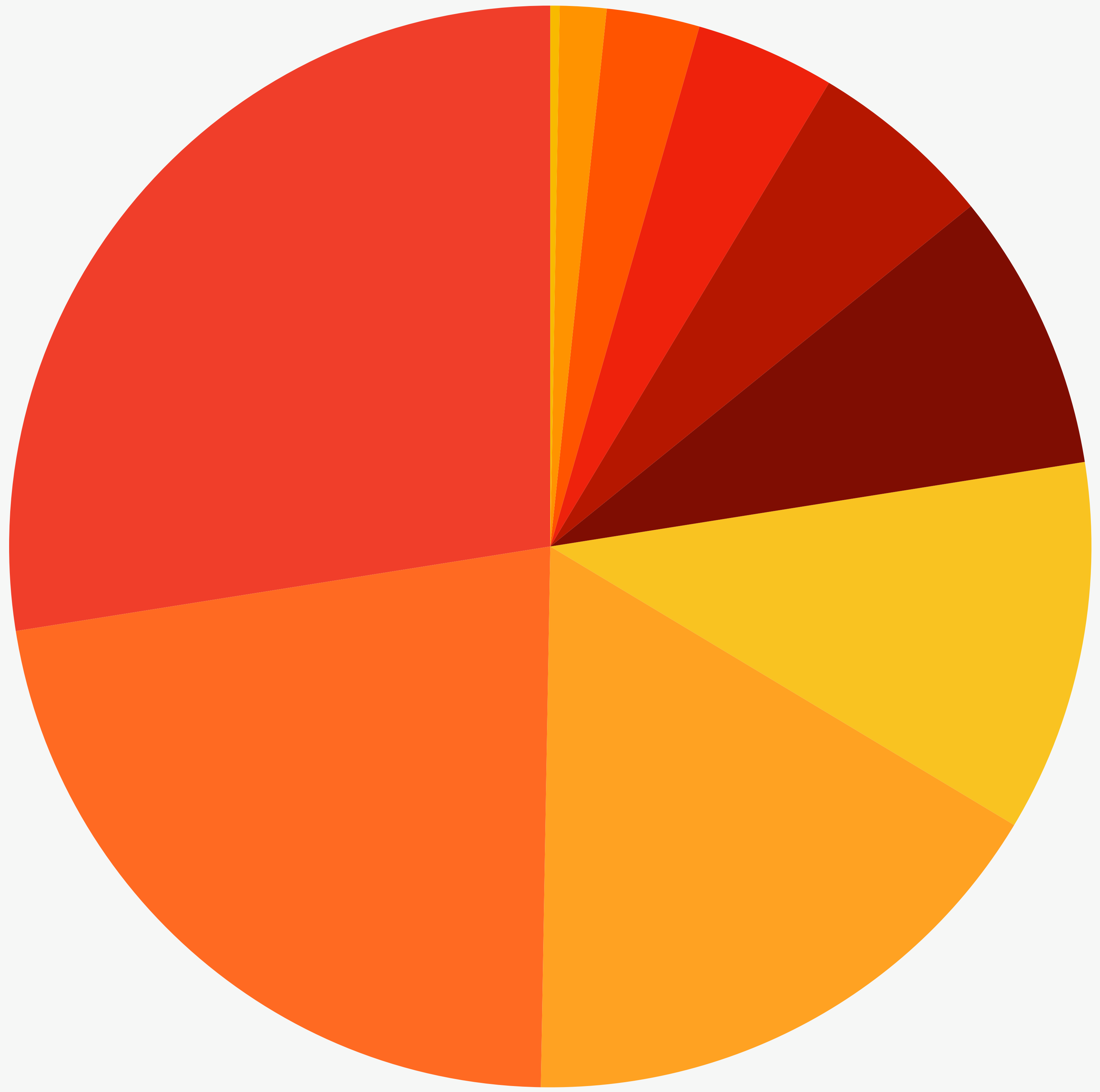
- Evaluate performance
- Reward behavior
- Punishment
- Weighted criteria

Selection

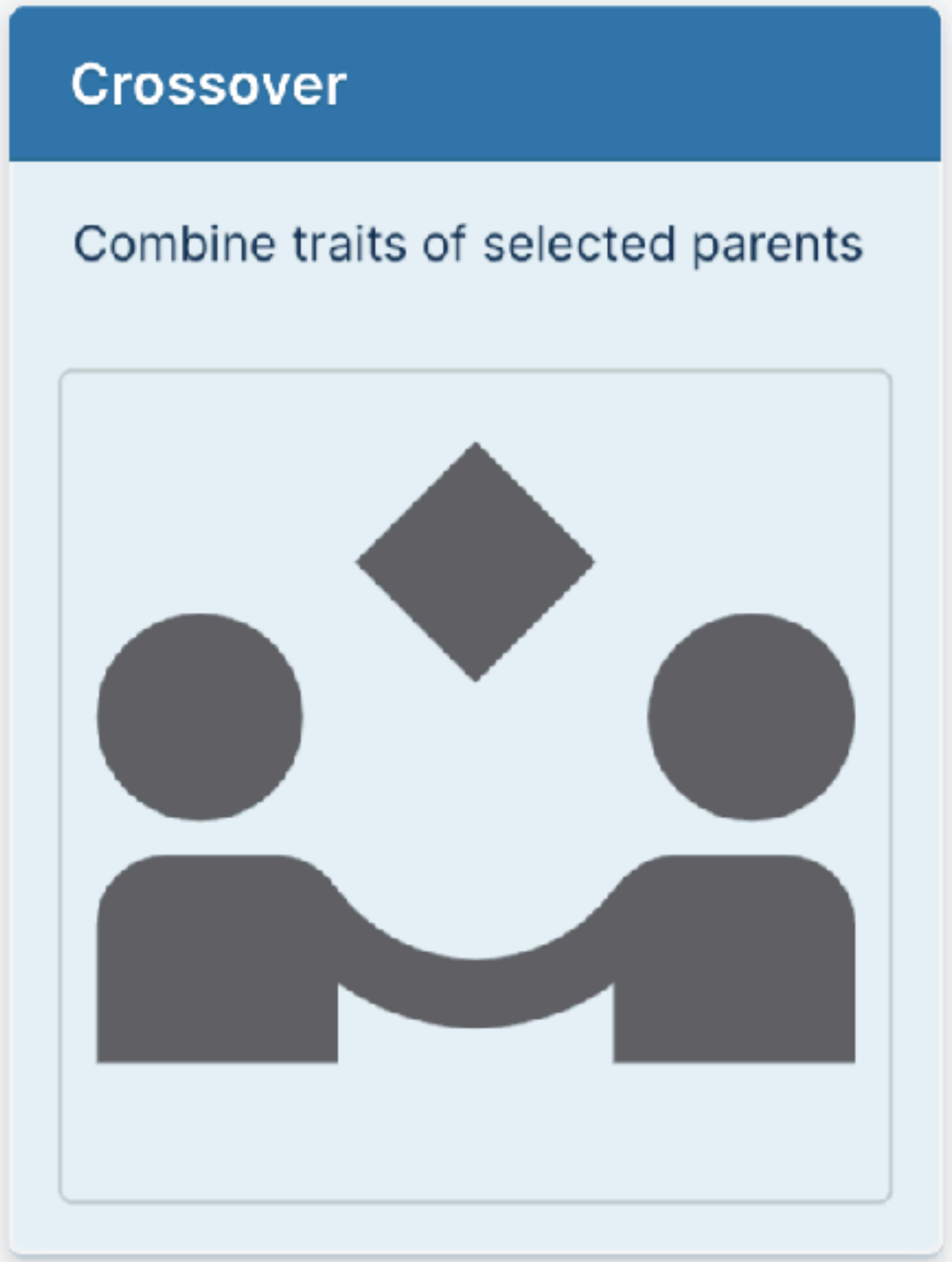
Selection

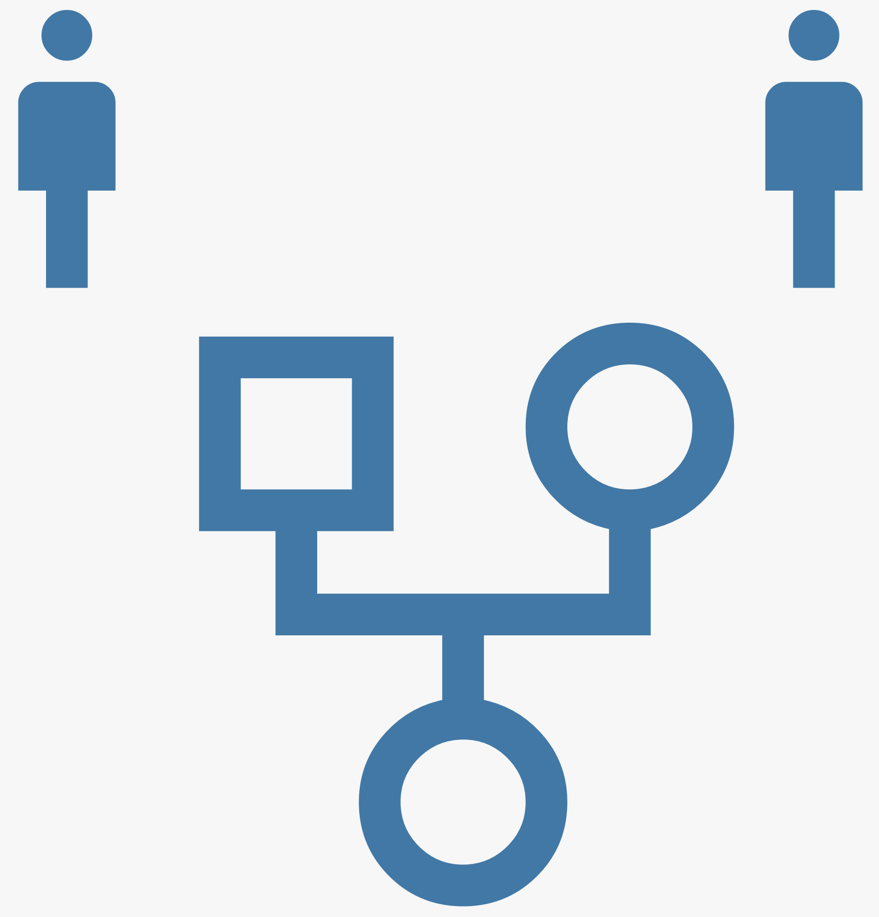
Select a subset of the population

Roulette Wheel Selection



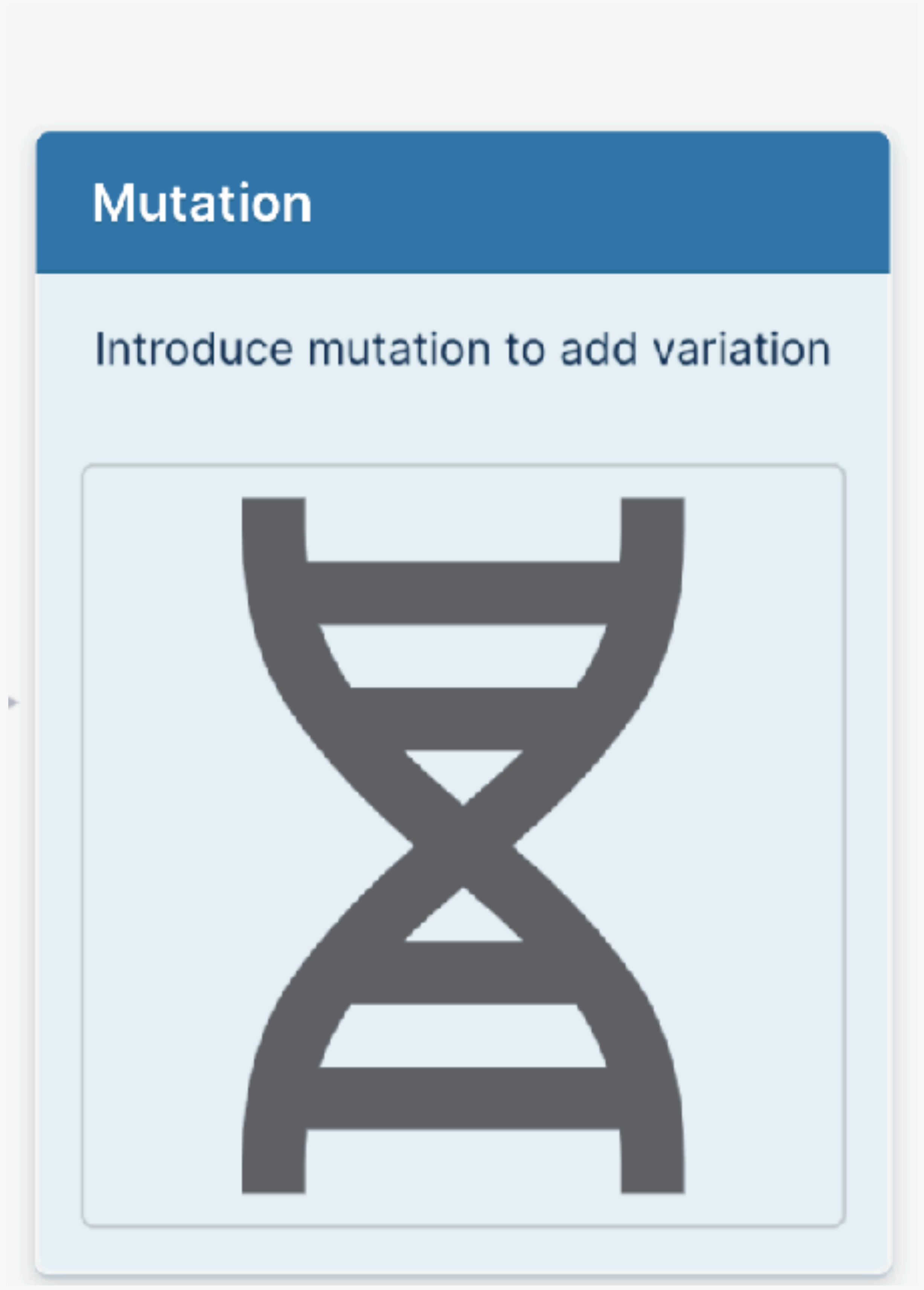
Crossover





x total population size

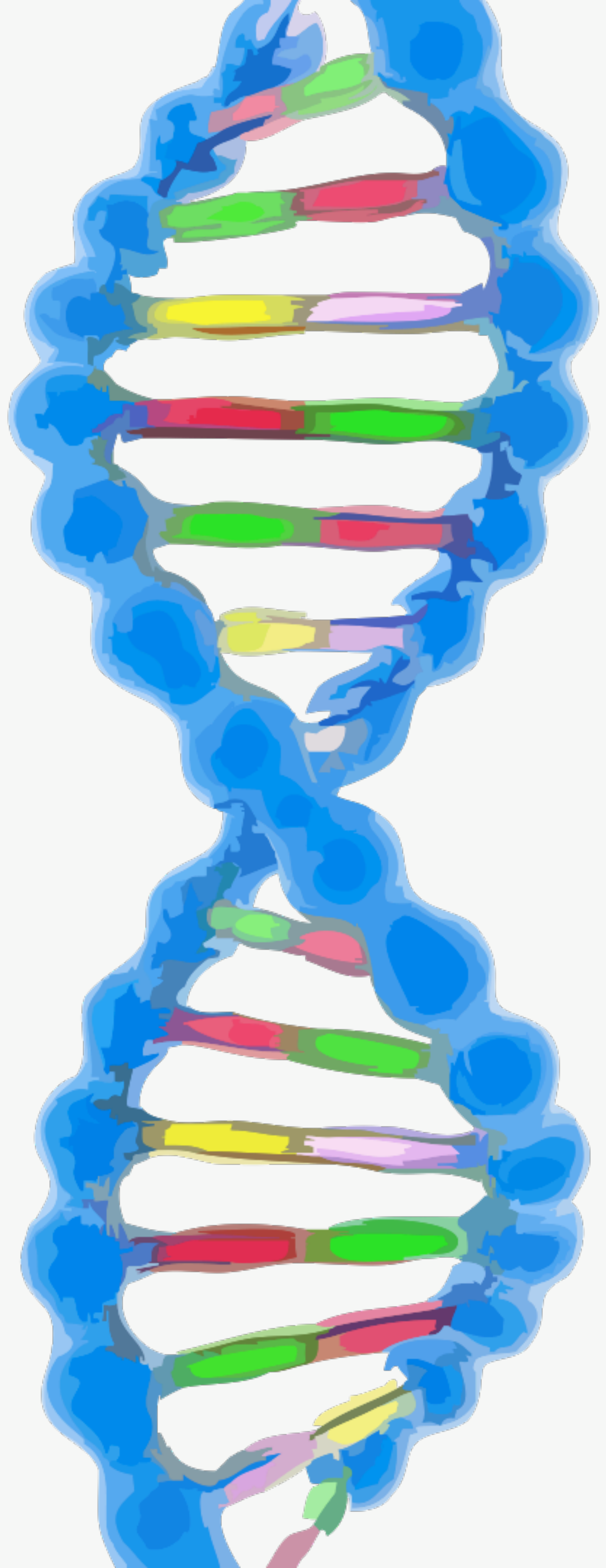
Mutation


Mutation

Introduce mutation to add variation

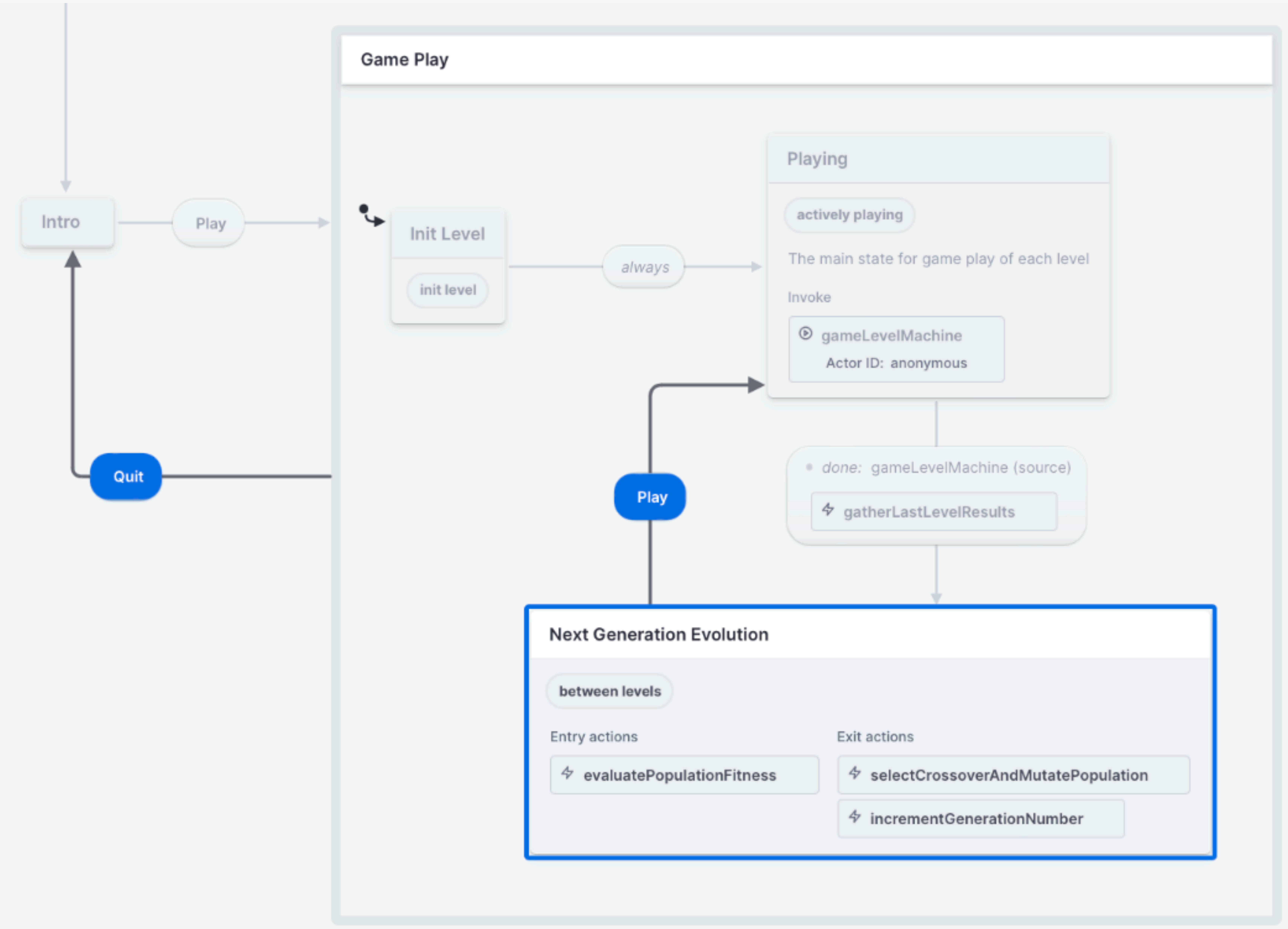
- Need to maintain variation
- Avoid “local optima”
- Strive for the “global optimum”
- Mutation rate
- Mutation amount

GENETIC ALGORITHMS IN EGG DROP



HENDIVIDUAL

```
export interface Hendividual {
  id: string;
  // Configuration
  initialPosition: Position;
  speed: number;
  baseTweenDurationSeconds: number;
  maxEggs: number;
  stationaryEggLayingRate: number;
  movingEggLayingRate: number;
  restAfterLayingEggMS: number;
  blackEggRate: number;
  goldEggRate: number;
  hatchRate: number;
  minX: number;
  maxX: number;
  minStopMS: number;
  maxStopMS: number;
```


Game Play
Intro
Play
Init Level
init level
always
Playing
actively playing
The main state for game play of each level
Invoke
gameLevelMachine
Actor ID: anonymous
done: gameLevelMachine (source)
gatherLastLevelResults
Quit
Play
Next Generation Evolution
between levels
Entry actions
evaluatePopulationFitness
Exit actions
selectCrossoverAndMutatePopulation
incrementGenerationNumber

Evaluation & Fitness

Evaluate performance

Reward behavior →

- Hens that lay more eggs
- Hens whose eggs go uncaught
- Hens whose black eggs get caught

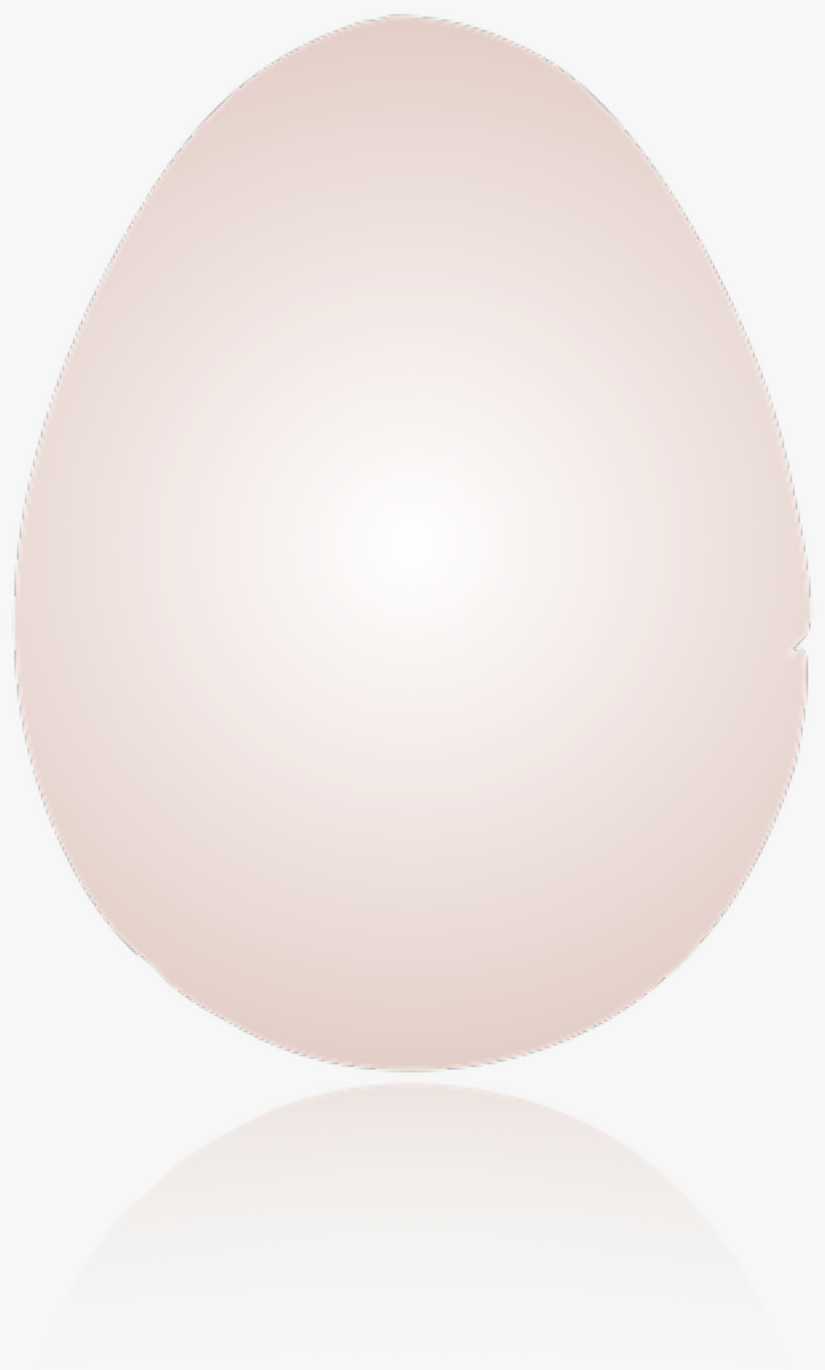
Punishment →

- Hens who don’t lay any eggs at all

Weighted criteria

LEVEL 1
34s
SCORE
93
13
8
×
TOTAL SCORE
93

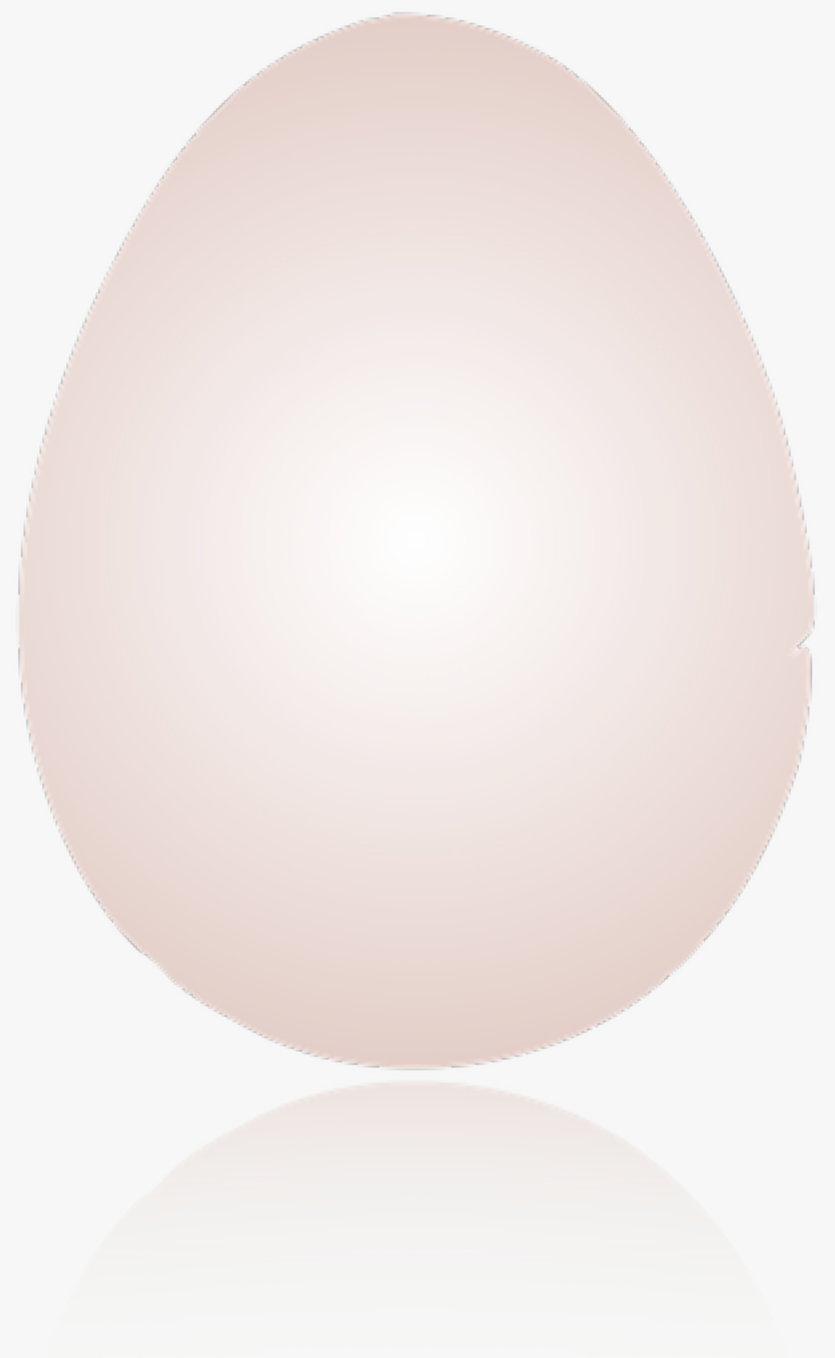
TWEAK THE GA



BUILD THE GAME

TWEAK THE GA

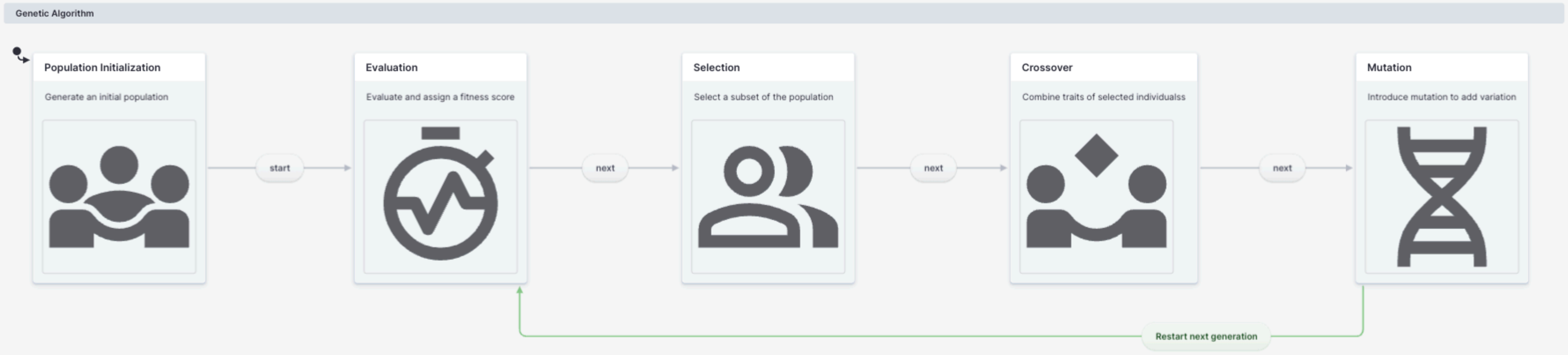
OR



LEVEL 1
55s
SCORE
0
×
×
1
TOTAL SCORE
0

LEVEL 1
6
SCORE
14
4
1
×
TOTAL SCORE
14

Overcome small population size


Genetic Algorithm
Population Initialization
Generate an initial population
start
Evaluation
Evaluate and assign a fitness score
next
Selection
Select a subset of the population
next
Crossover
Combine traits of selected individualss
next
Mutation
Introduce mutation to add variation
Restart next generation

Add genes (traits)

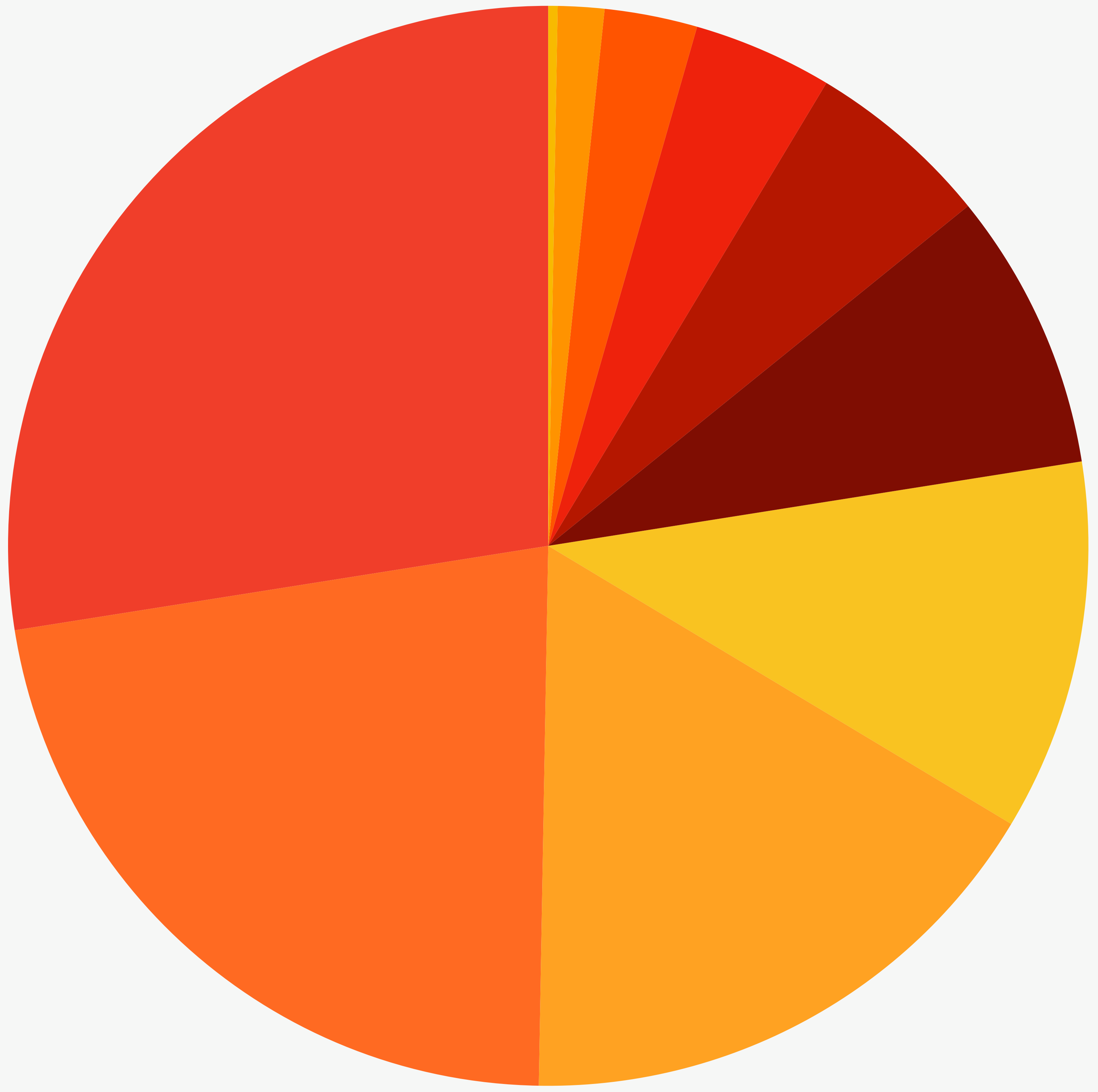
Tweak Fitness

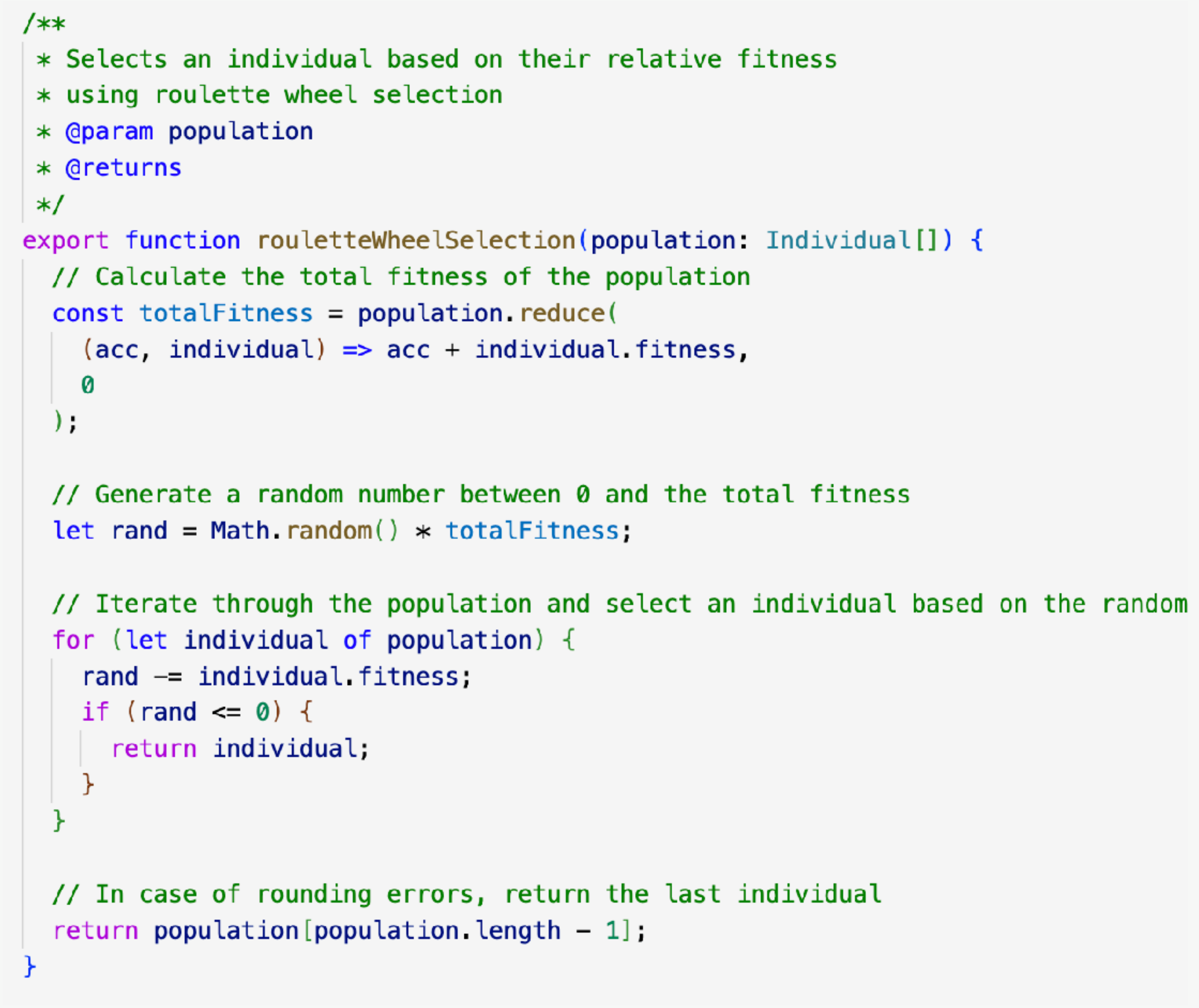
Introduce elitism

Hybrid averaging/selection

Increase rate

Roulette Wheel Selection





```typescript
/**
 * Selects an individual based on their relative fitness
 * using roulette wheel selection
 * @param population
 * @returns
 */
export function rouletteWheelSelection(population: Individual[]) {
  // Calculate the total fitness of the population
  const totalFitness = population.reduce(
    (acc, individual) => acc + individual.fitness,
    0
  );

  // Generate a random number between 0 and the total fitness
  let rand = Math.random() * totalFitness;

  // Iterate through the population and select an individual based on the random
  for (let individual of population) {
    rand -= individual.fitness;
    if (rand <= 0) {
      return individual;
    }
  }

  // In case of rounding errors, return the last individual
  return population[population.length - 1];
}
```

Hendividual DNA (genes)

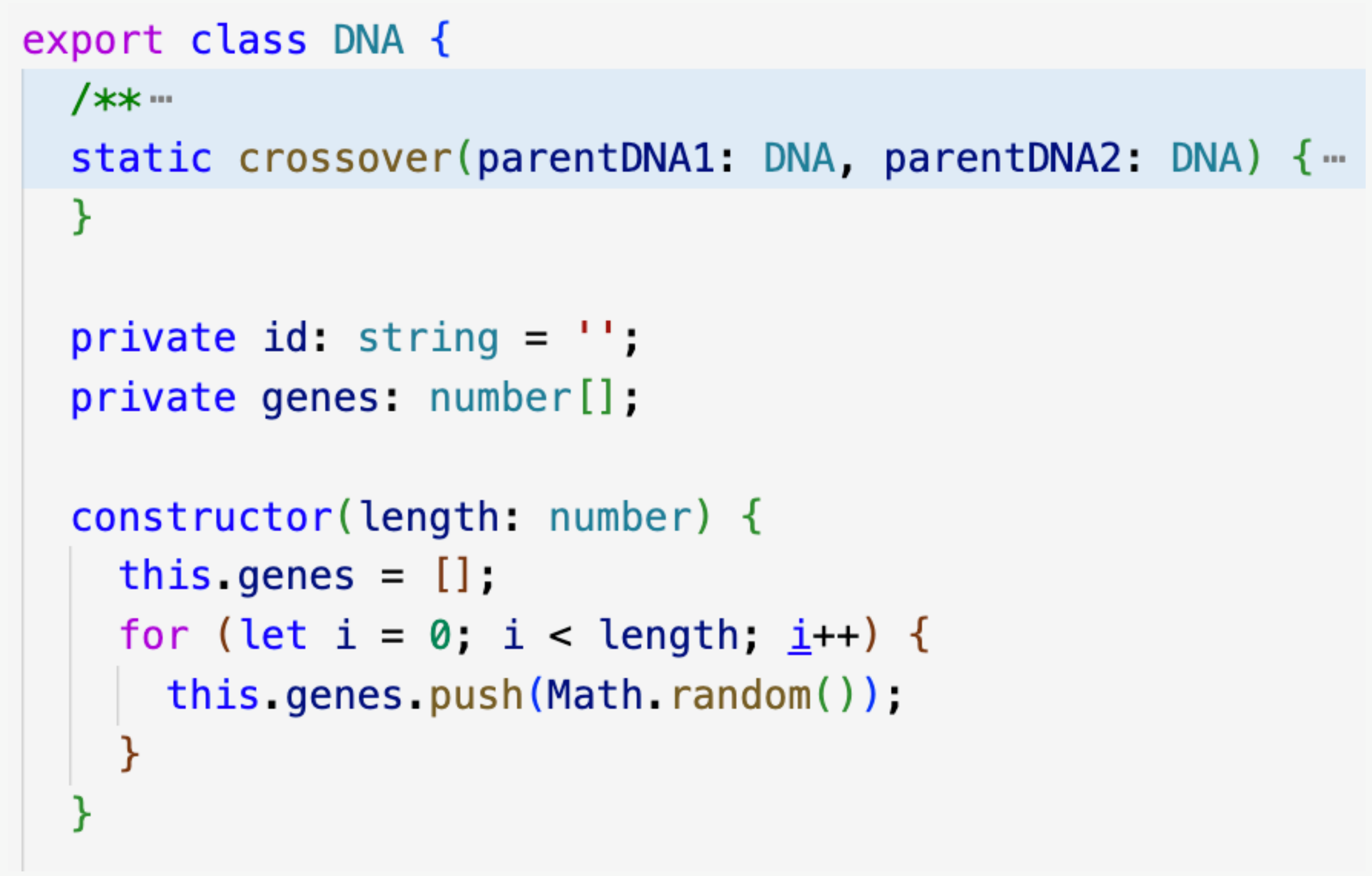
GENOTYPE

0.97	0.32	0.37	0.28	0.83	0.04	0.26	0.98

PHENOTYPE

{ SPEED, COLOR, SIZE, ... }

Hendividual DNA (genes)



```
export class DNA {
  /** ...
  static crossover(parentDNA1: DNA, parentDNA2: DNA) { ...
  }

  private id: string = '';
  private genes: number[];

  constructor(length: number) {
    this.genes = [];
    for (let i = 0; i < length; i++) {
      this.genes.push(Math.random());
    }
  }
```

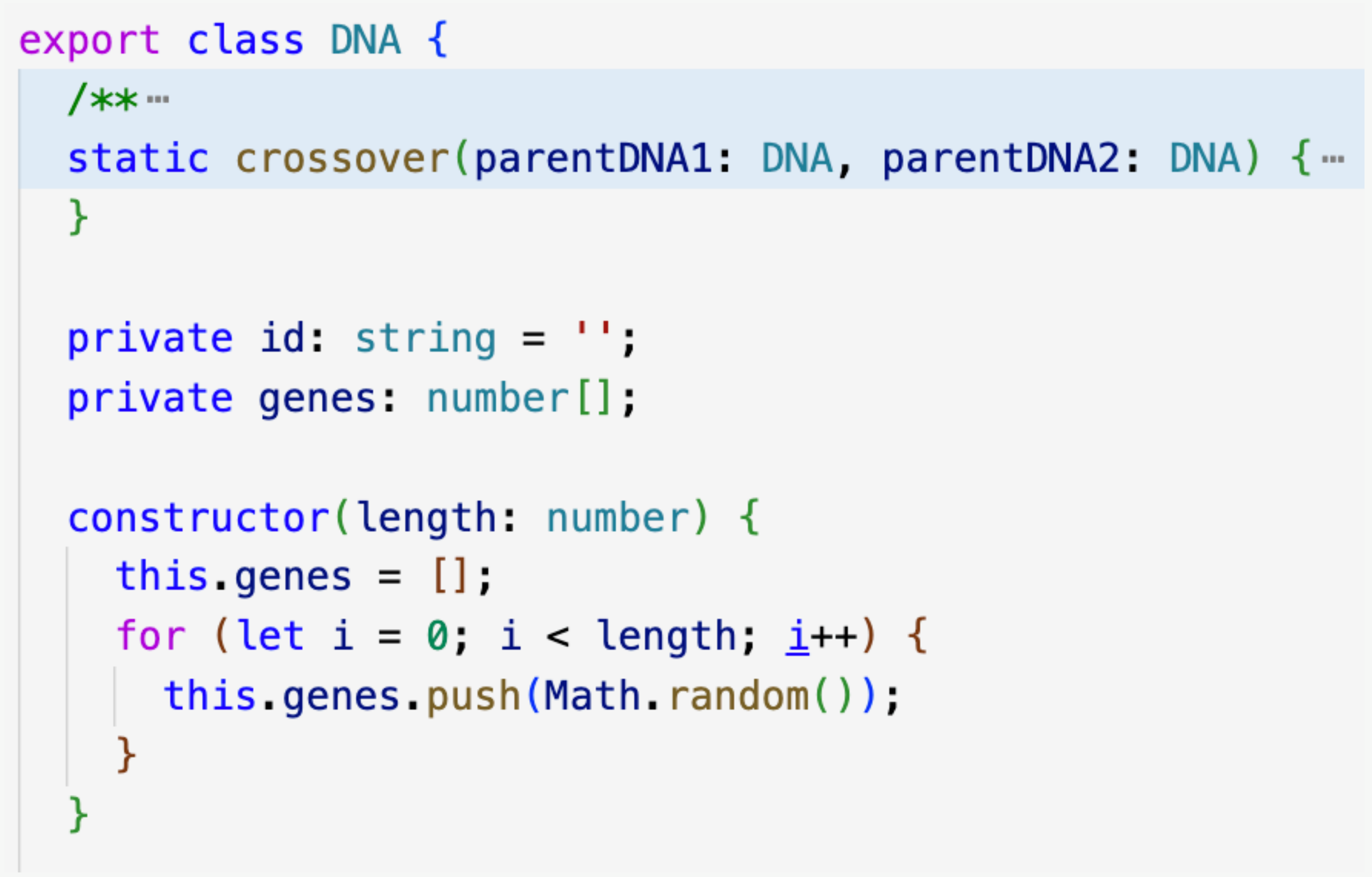
PARENT 1

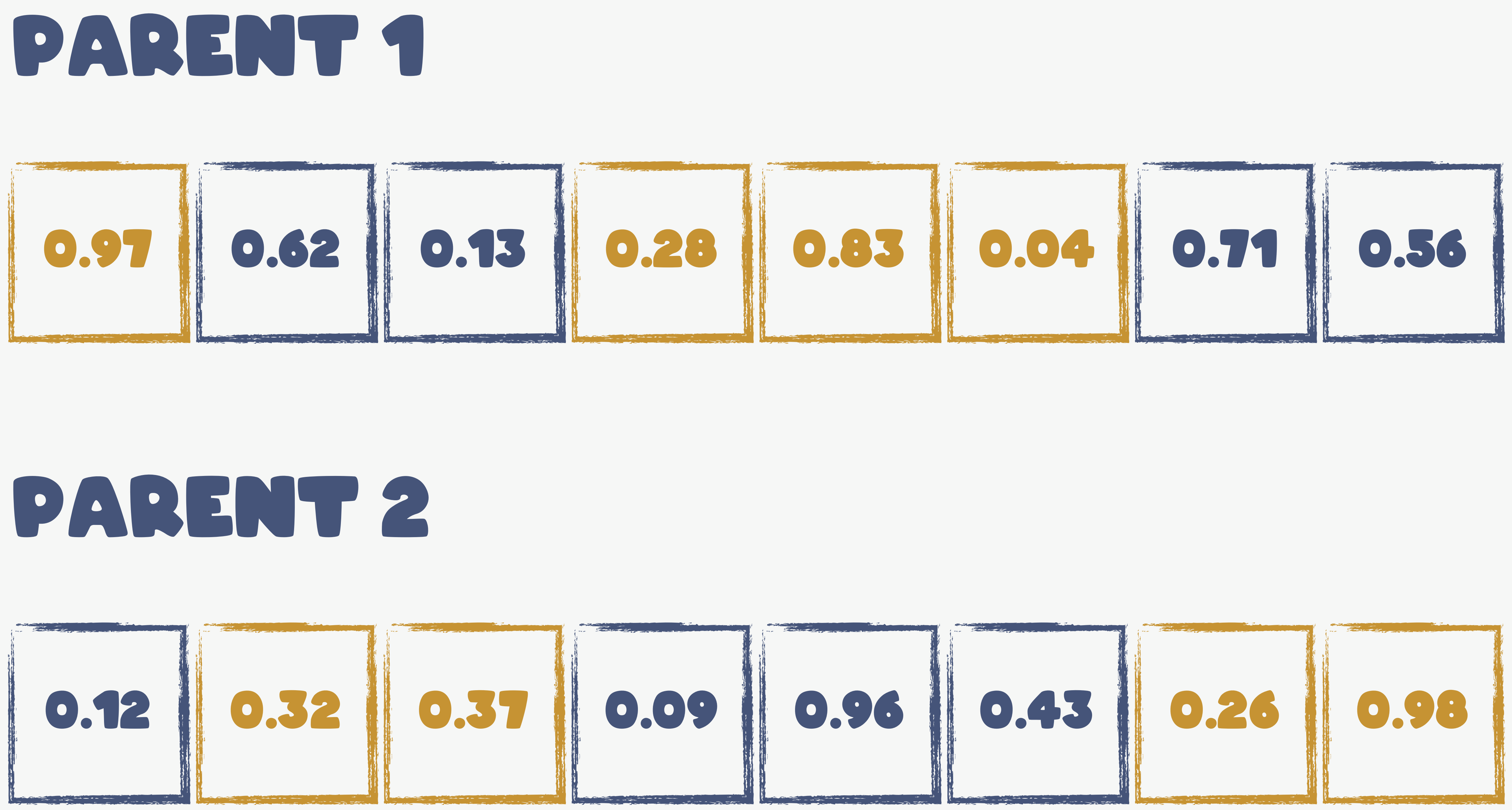
0.97	0.62	0.13	0.28	0.83	0.04	0.71	0.56

PARENT 2

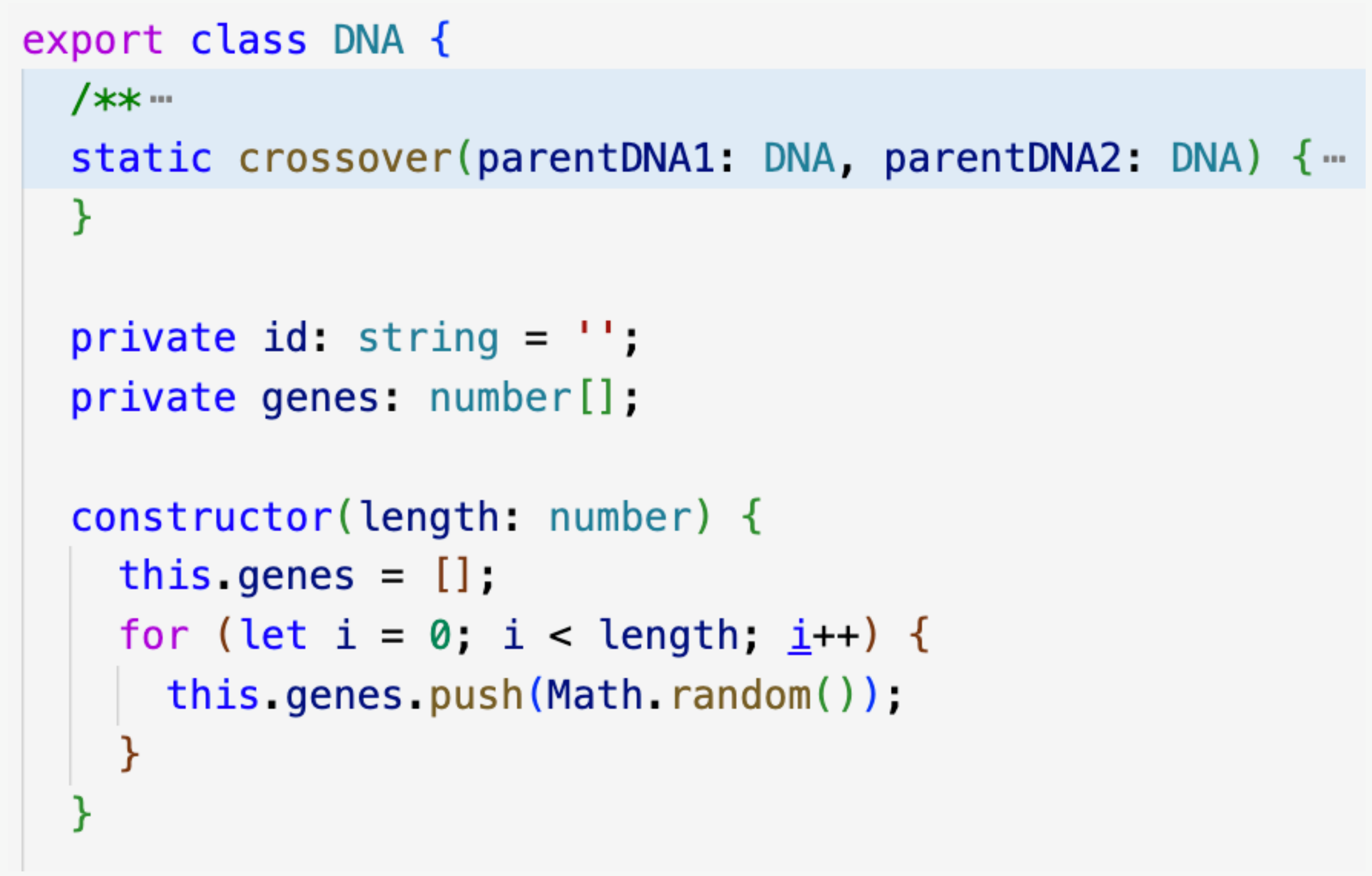
0.12	0.32	0.37	0.09	0.96	0.43	0.26	0.98

Hendividual DNA (genes)

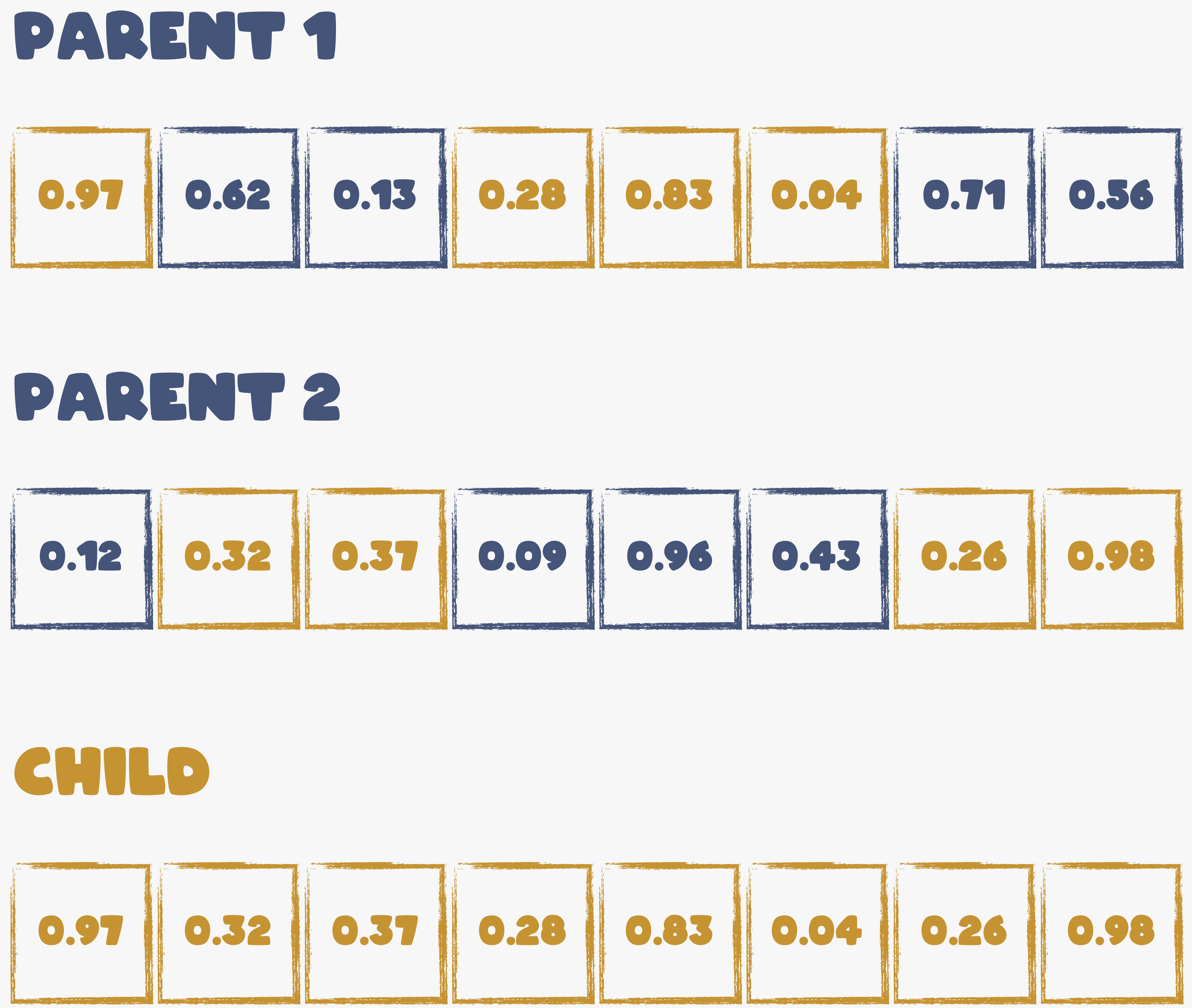

```
export class DNA {
  /**…
  static crossover(parentDNA1: DNA, parentDNA2: DNA) {…
  }

  private id: string = '';
  private genes: number[];

  constructor(length: number) {
    this.genes = [];
    for (let i = 0; i < length; i++) {
      this.genes.push(Math.random());
    }
  }
```



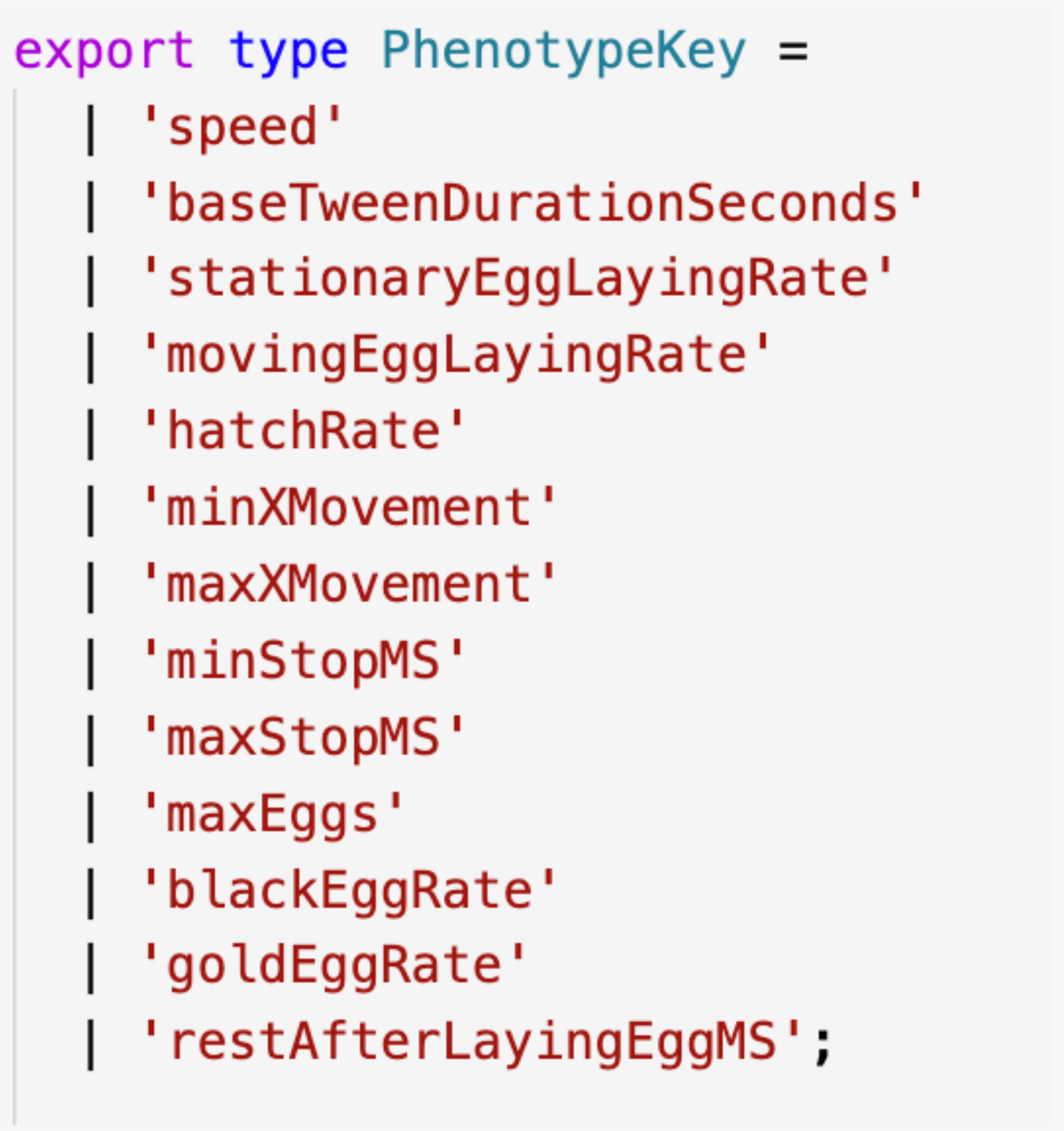
Hendividual DNA (genes)



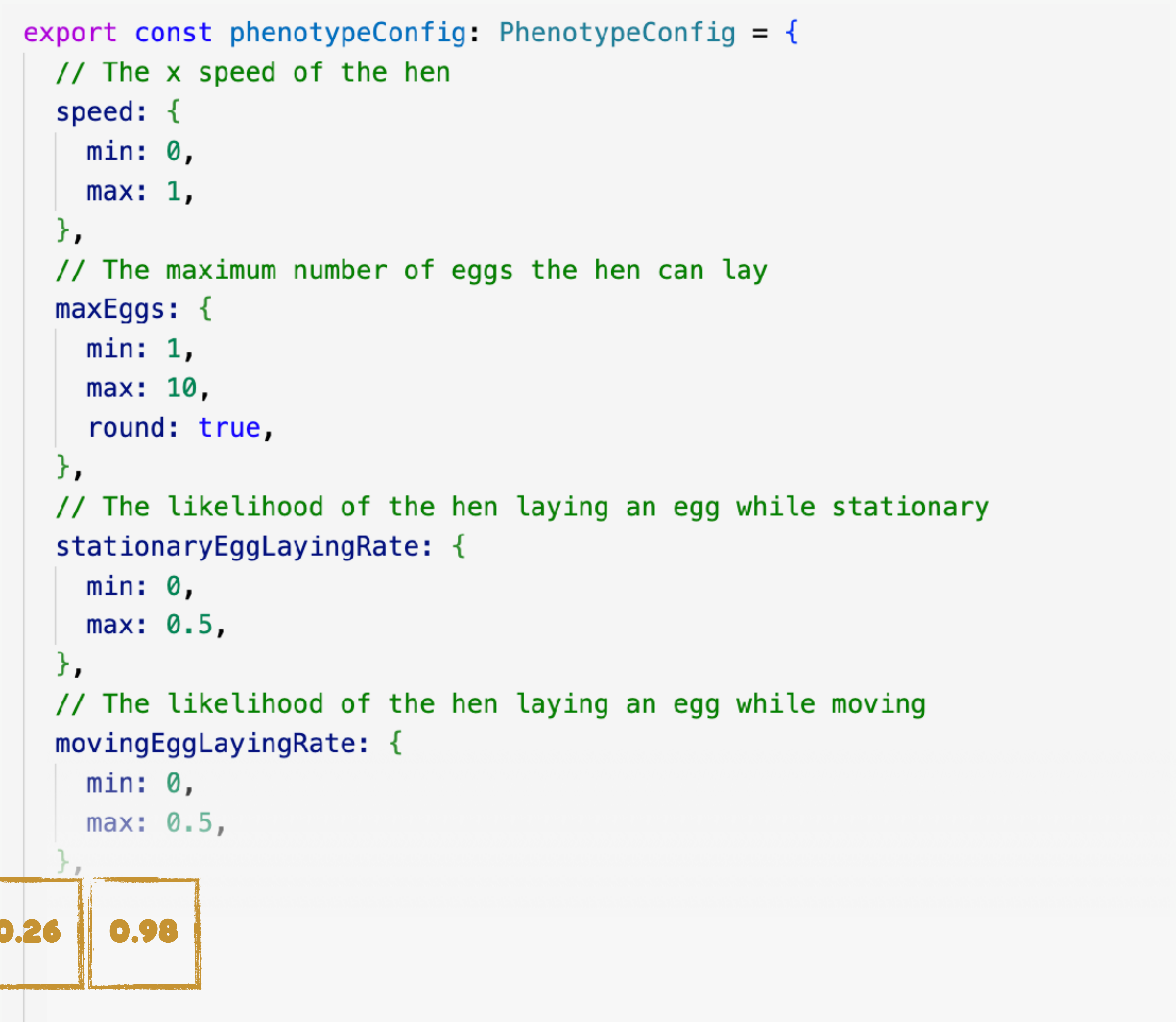
```
export class DNA {
  /**…
  static crossover(parentDNA1: DNA, parentDNA2: DNA) {…
  }

  private id: string = '';
  private genes: number[];

  constructor(length: number) {
    this.genes = [];
    for (let i = 0; i < length; i++) {
      this.genes.push(Math.random());
    }
  }
```



AGNOSTIC OF PHENOTYPE VALUES →



```typescript
export type PhenotypeKey =
  | 'speed'
  | 'baseTweenDurationSeconds'
  | 'stationaryEggLayingRate'
  | 'movingEggLayingRate'
  | 'hatchRate'
  | 'minXMovement'
  | 'maxXMovement'
  | 'minStopMS'
  | 'maxStopMS'
  | 'maxEggs'
  | 'blackEggRate'
  | 'goldEggRate'
  | 'restAfterLayingEggMS';
```



```typescript
export const phenotypeConfig: PhenotypeConfig = {
  // The x speed of the hen
  speed: {
    min: 0,
    max: 1,
  },
  // The maximum number of eggs the hen can lay
  maxEggs: {
    min: 1,
    max: 10,
    round: true,
  },
  // The likelihood of the hen laying an egg while stationary
  stationaryEggLayingRate: {
    min: 0,
    max: 0.5,
  },
  // The likelihood of the hen laying an egg while moving
  movingEggLayingRate: {
    min: 0,
    max: 0.5,
  },
```

CHILD

0.97	0.32	0.37	0.28	0.83	0.04	0.26	0.98

```typescript
/** Genetic Algorithm individual of the population */
export interface Individual {
  dna: DNA;
  phenotype: Record<PhenotypeKey, number>;
  fitness: number;
}
```

```typescript
/** Hendividual = Hen + Individual for Egg Drop */
export interface Hendividual extends Individual {
  id: string;

  // Configuration
  initialPosition: Position;

  // Results
  stats: {
    eggsLaid: number;
    eggsCaught: {
      white: number;
      gold: number;
      black: number;
    };
    eggsHatched: number;
    eggsBroken: number;
    eggsOffscreen: number;
  };
}
```

LEVEL 3
36
SCORE
39
16
3
2
TOTAL SCORE
93

EGG DROP

Test sound

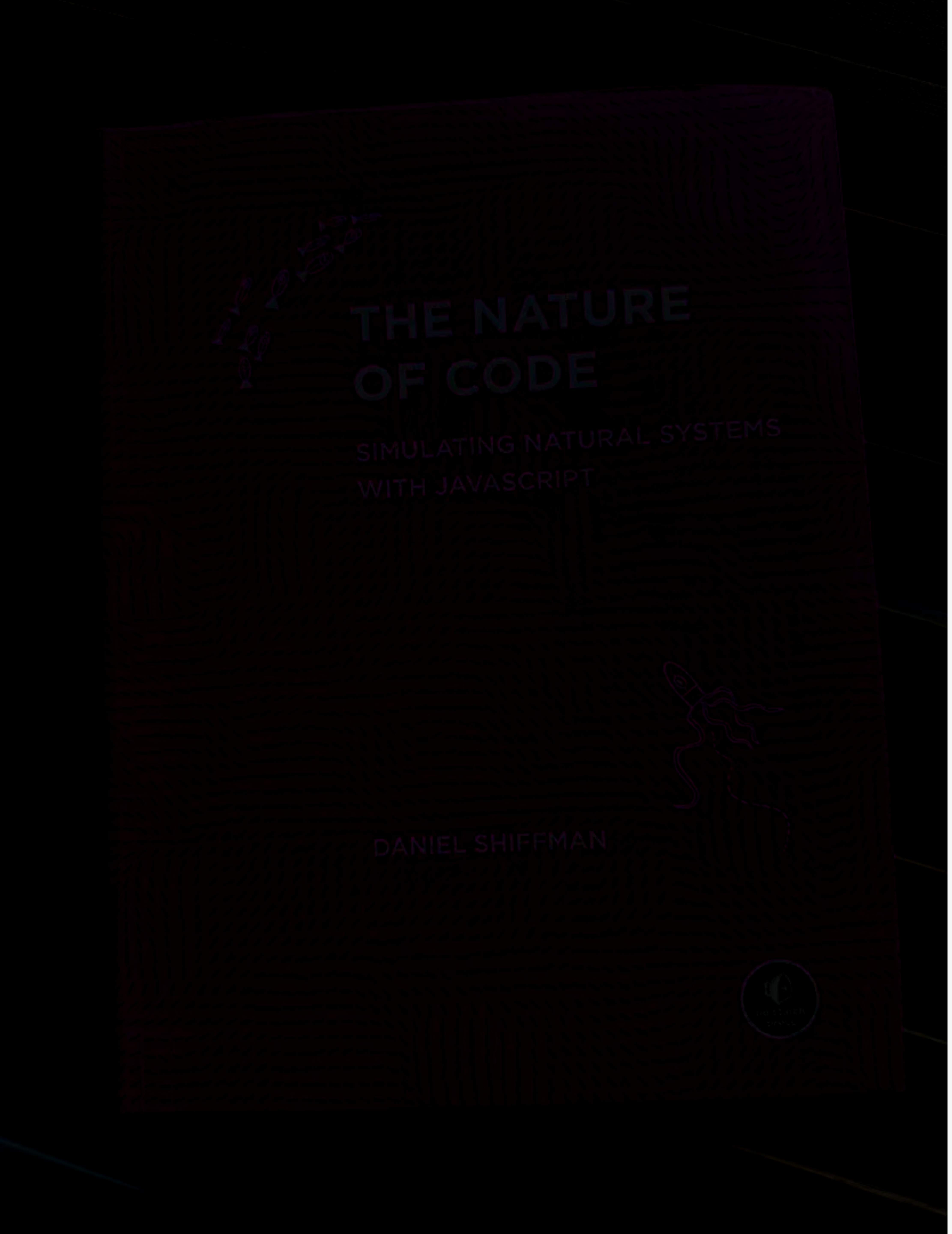
Generation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
totalEggsLaid	68	76	96	88	95	79	72	57	73	75	80	67	73	68	60	73
averageEggsLaid	1.7	1.9	2.4	2.2	2.4	2.0	1.8	1.4	1.8	1.9	2.0	1.7	1.8	1.7	1.5	1.8
catchRate	35%	38%	30%	27%	36%	33%	39%	37%	27%	28%	29%	36%	38%	21%	25%	29%
averageFitness	0.78	0.89	1.03	0.95	0.95	0.90	0.88	0.79	0.90	0.94	1.02	0.84	0.83	1.06	0.88	0.92
averageHenSpeed ↗	0.51	0.71	0.74	0.75	0.81	0.80	0.85	0.91	0.94	0.95	0.96	0.96	0.98	0.98	0.98	0.98
averageBaseTweenDurationSeconds	3	3	4	4	4	4	4	5	5	5	5	5	5	5	5	5
averageStationaryEggLayingRate ↗	0.25	0.36	0.37	0.38	0.40	0.40	0.43	0.46	0.47	0.48	0.48	0.48	0.49	0.49	0.49	0.49
averageMovingEggLayingRate ↗	0.25	0.36	0.37	0.38	0.40	0.40	0.43	0.46	0.47	0.48	0.48	0.48	0.49	0.49	0.49	0.49
averageHatchRate	0.5	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
averageMinXMovement ↗	126	156	160	163	171	170	178	187	191	193	194	195	197	197	197	197
averageMaxXMovement ↗	771	982	1,009	1,025	1,084	1,076	1,127	1,188	1,219	1,229	1,235	1,242	1,258	1,258	1,258	1,258
averageMinStopMS ↗	506	711	737	753	810	802	852	911	941	951	956	964	979	979	979	979
averageMaxStopMS ↗	2,532	3,557	3,684	3,762	4,049	4,011	4,259	4,552	4,704	4,755	4,780	4,818	4,894	4,894	4,894	4,894
averageMaxEggs ↗	5.5	7.4	7.6	7.8	8.4	8.3	8.8	9.3	9.6	9.7	9.8	9.9	10.0	10.0	10.0	10.0
averageBlackEggRate ↗	0.15	0.21	0.22	0.23	0.24	0.24	0.26	0.27	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29
averageGoldEggRate ↗	0.25	0.36	0.37	0.38	0.40	0.40	0.43	0.46	0.47	0.48	0.48	0.48	0.49	0.49	0.49	0.49
averageRestAfterLayingEggMS	1,013	1,423	1,474	1,505	1,620	1,604	1,704	1,821	1,882	1,902	1,912	1,928	1,958	1,958	1,958	1,958

Test sound

Generation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
totalEggsLaid	68	76	96	88	95	79	72	57	73	75	80	67	73	68	60	73
averageEggsLaid	1.7	1.9	2.4	2.2	2.4	2.0	1.8	1.4	1.8	1.9	2.0	1.7	1.8	1.7	1.5	1.8
catchRate	35%	38%	30%	27%	36%	33%	39%	37%	27%	28%	29%	36%	38%	21%	25%	29%
averageFitness	0.78	0.89	1.03	0.95	0.95	0.90	0.88	0.79	0.90	0.94	1.02	0.84	0.83	1.06	0.88	0.92
averageHenSpeed	0.51	0.71	0.74	0.75	0.81	0.80	0.85	0.91	0.94	0.95	0.96	0.96	0.98	0.98	0.98	0.98
averageBaseTweenDurationSeconds	3	3	4	4	4	4	4	5	5	5	5	5	5	5	5	5
averageStationaryEggLayingRate	0.25	0.36	0.37	0.38	0.40	0.40	0.43	0.46	0.47	0.48	0.48	0.48	0.49	0.49	0.49	0.49
averageMovingEggLayingRate	0.25	0.36	0.37	0.38	0.40	0.40	0.43	0.46	0.47	0.48	0.48	0.48	0.49	0.49	0.49	0.49
averageHatchRate	0.5	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
averageMinXMovement	126	156	160	163	171	170	178	187	191	193	194	195	197	197	197	197
averageMaxXMovement	771	982	1,009	1,025	1,084	1,076	1,127	1,188	1,219	1,229	1,235	1,242	1,258	1,258	1,258	1,258
averageMinStopMS	506	711	737	753	810	802	852	911	941	951	956	964	979	979	979	979
averageMaxStopMS	2,532	3,557	3,684	3,762	4,049	4,011	4,259	4,552	4,704	4,755	4,780	4,818	4,894	4,894	4,894	4,894
averageMaxEggs	5.5	7.4	7.6	7.8	8.4	8.3	8.8	9.3	9.6	9.7	9.8	9.9	10.0	10.0	10.0	10.0
averageBlackEggRate	0.15	0.21	0.22	0.23	0.24	0.24	0.26	0.27	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29
averageGoldEggRate	0.25	0.36	0.37	0.38	0.40	0.40	0.43	0.46	0.47	0.48	0.48	0.48	0.49	0.49	0.49	0.49
averageRestAfterLayingEggMS	1,013	1,423	1,474	1,505	1,620	1,604	1,704	1,821	1,882	1,902	1,912	1,928	1,958	1,958	1,958	1,958

SUMMARY

1. GENETIC ALGORITHMS
2. HOW TO CREATE A GAME
3. HOW TO INCLUDE A GA



GET THIS BOOK!

The Nature of Code

Daniel Shiffman

thecodingtrain.com/

LEVEL 2
39
SCORE
TOTAL SCORE

STATELY

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Kevin Maes