

Quantum Game with Photons: Tensors in TypeScript, Visualized

Piotr Migdał
p.migdal.pl / @pmigdal

Project funded by:
Centre for Quantum Technologies, National University of Singapore
& Unitary Fund

Quantum Computing devroom, FOSDEM'20
1 Feb 2020, Brussels, Belgium



PhD in quantum physics
Maciej Lewenstein's group
(2014, ICFO, Castelldefels)

data science
freelance consultant:

machine learning
deep learning
data-viz
trainings

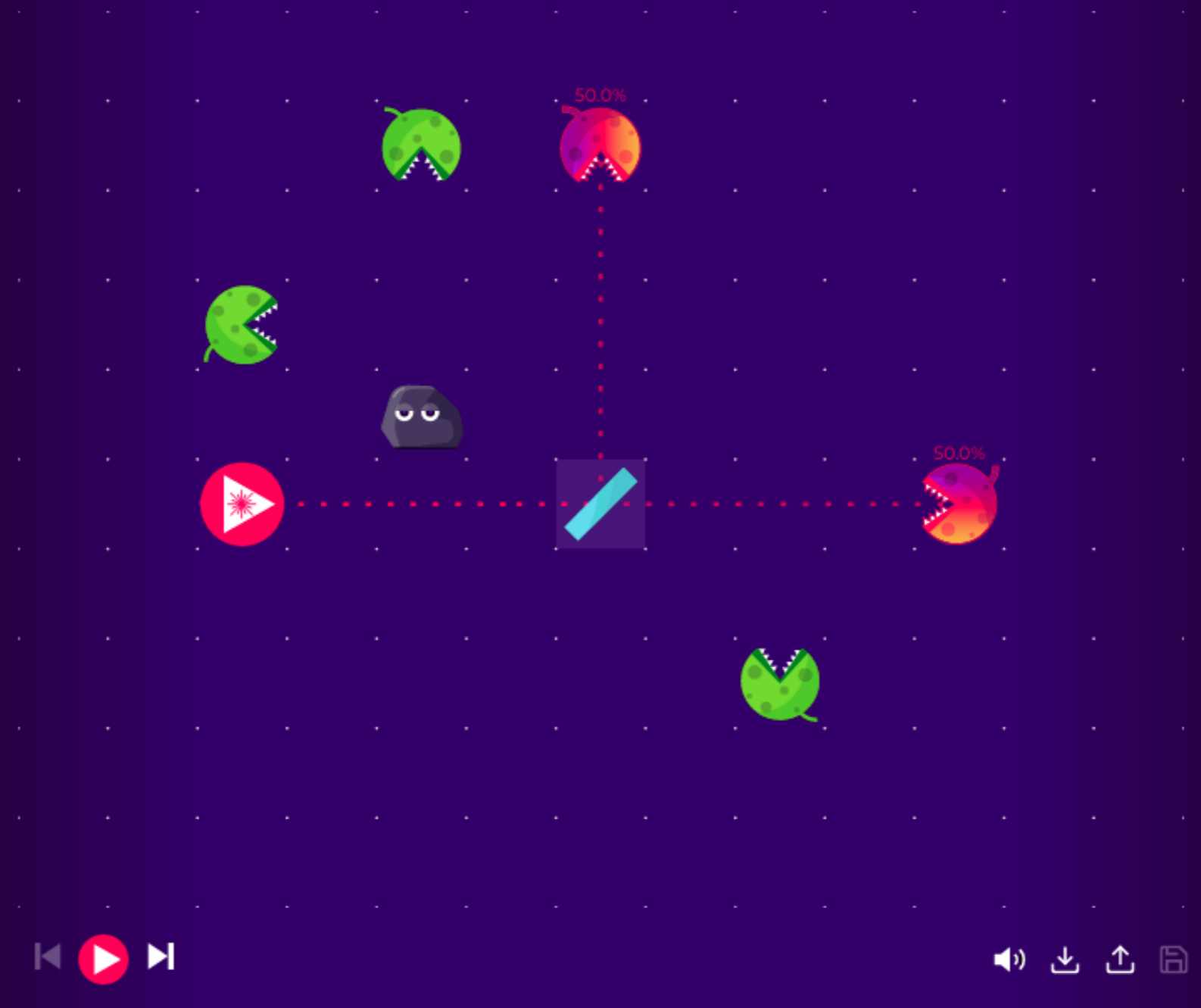
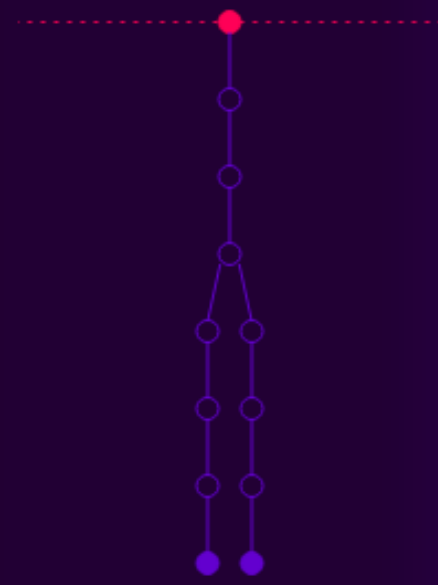




2 - DIVIDE AND CONQUER!

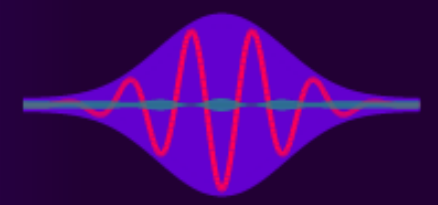


Goal: 87.5 %



3 (4)

PHOTON



Ket: $(1.00 + 0.00 i) | \rightarrow H \rangle$

POLAR CARTESIAN COLOR

$1.00 \exp(i0.00) | 2,5 \rightarrow H \rangle$

amplitude (complex number) x,y
coordinates direction polarization



<https://alpha.quantumgame.io>

Outline

- motivation
- inspiration
- the game / the tensors / the kets
- what's next (and how YOU can contribute)

Having fun



Norbert Rosing, National Geographic

Lookup YouTube videos for:

- dog + magpie
- cat + weasel

A child learns natural numbers...

- ...by playing with apples, toys?
- ...by understanding
the von Neumann construction?

A child learns classical mechanics...

- ...by playing with balls, blocks?
- ...by learning differential calculus?

A child learns quantum mechanics...

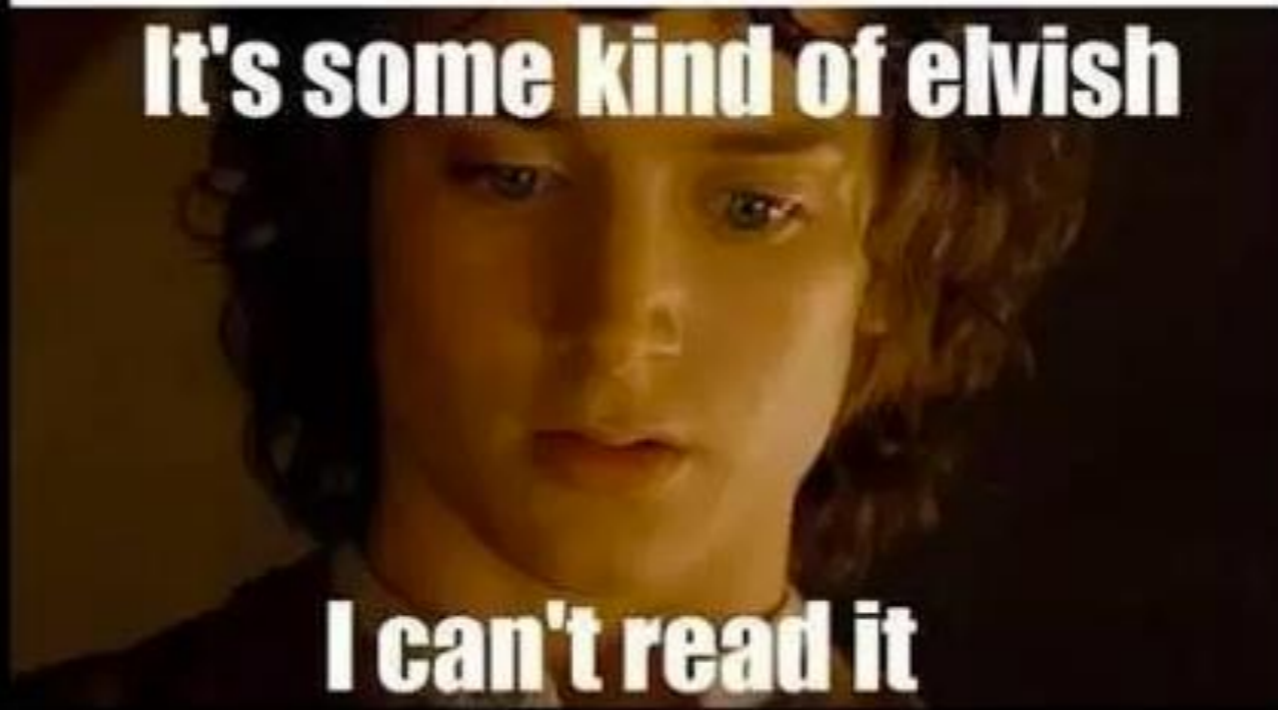
- ...by learning complex numbers
and linear operators?



$$i\hbar\dot{\psi} = \left(-\frac{\hbar^2}{2m}\nabla^2 + V(x) \right) \psi$$

$$\hat{H}\psi = E\psi$$

It's some kind of elvish



I can't read it

many-worlds

the very nature of reality

strange

consciousness

spooky

soul?

God?

free will

telepathy?

many-worlds

the very nature of reality

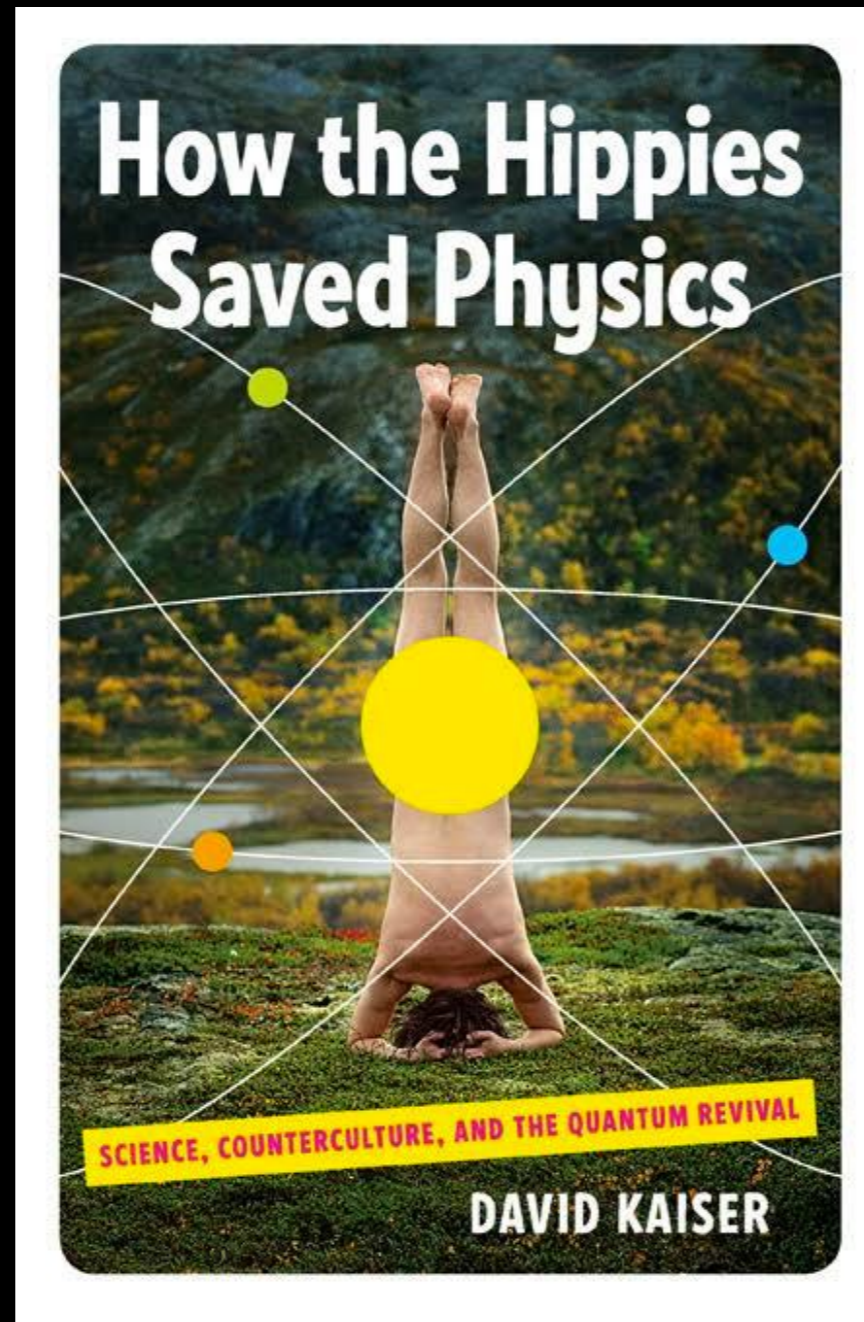
strange

consciousness

spooky

soul?

God?



telepathy?

free will

“To the layman, the philosopher,
or the classical physicist,
a statement of the form
“this particle doesn’t have a well-defined position” [...] sounds vague, incompetent,
or (worst of all) profound.
It is none of these.”

David J. Griffiths

“Common sense
is the collection of prejudices
acquired by age eighteen.”

Albert Einstein, probably

<https://quoteinvestigator.com/2014/04/29/common-sense/>

WAKACYJNE WARSZTATY WIERCHOMLA WIELKA WIELODyscyPLINARNE

17-28 sierpnia

Wierchomla Wielka

```
quick :: (Ord a) => [a] -> [a]
quick [] = []
quick (x:xs) =
  let smaller = quick (filter (<=x) xs)
      bigger = quick (filter (>x) xs)
  in smaller ++ [x] ++ bigger
```

```
polyval(x, coef):
sum = 0
while 1:
sum = sum + coef[0]
coef = coef[1:]
if not coef:
return sum
sum = sum * x
```

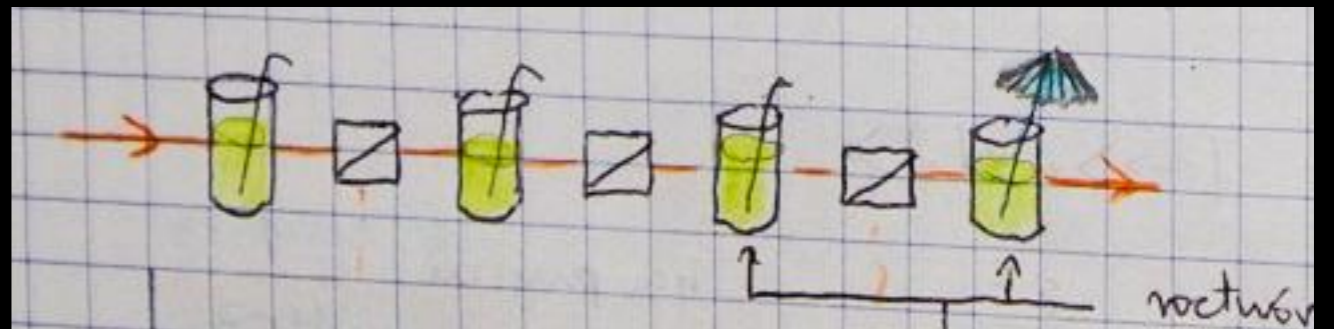
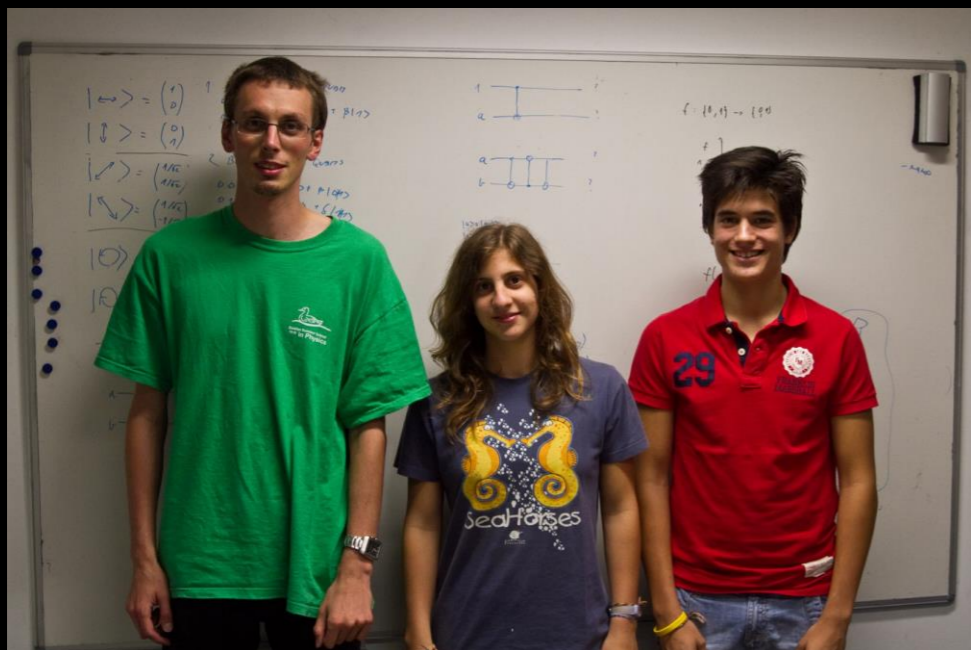
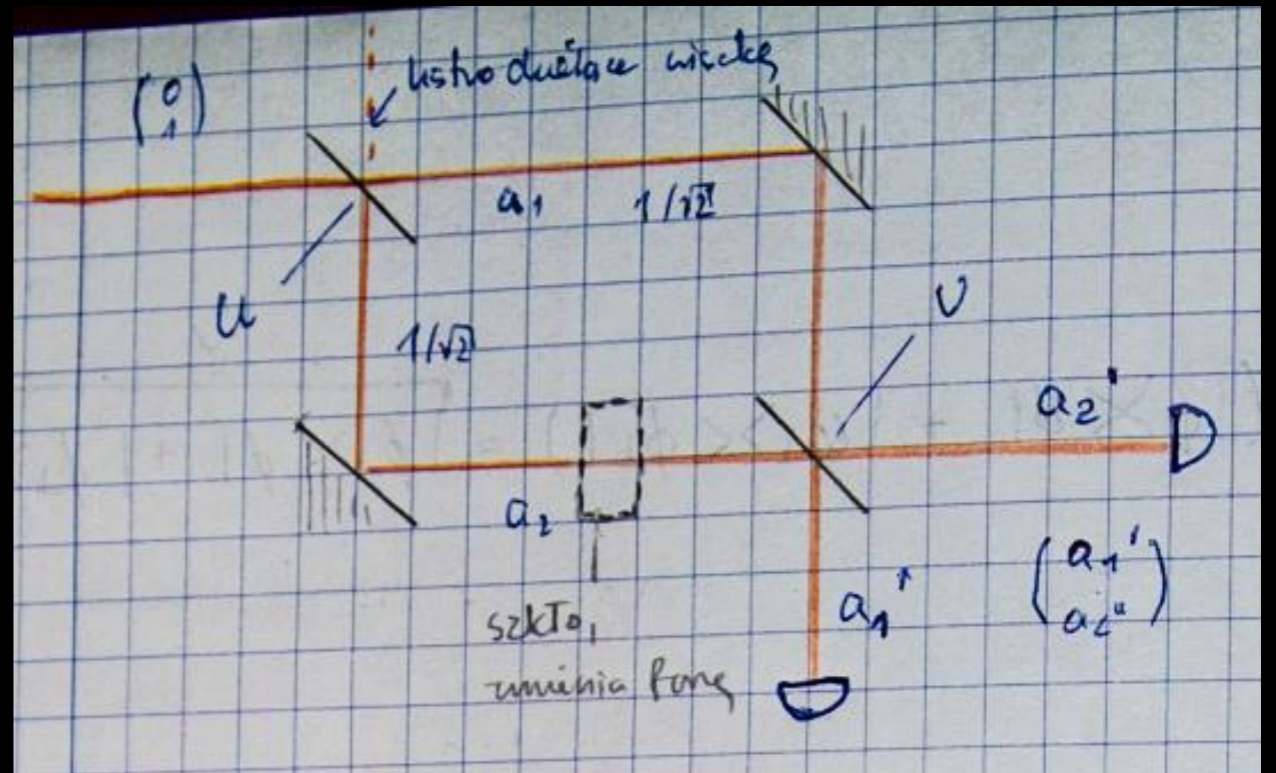
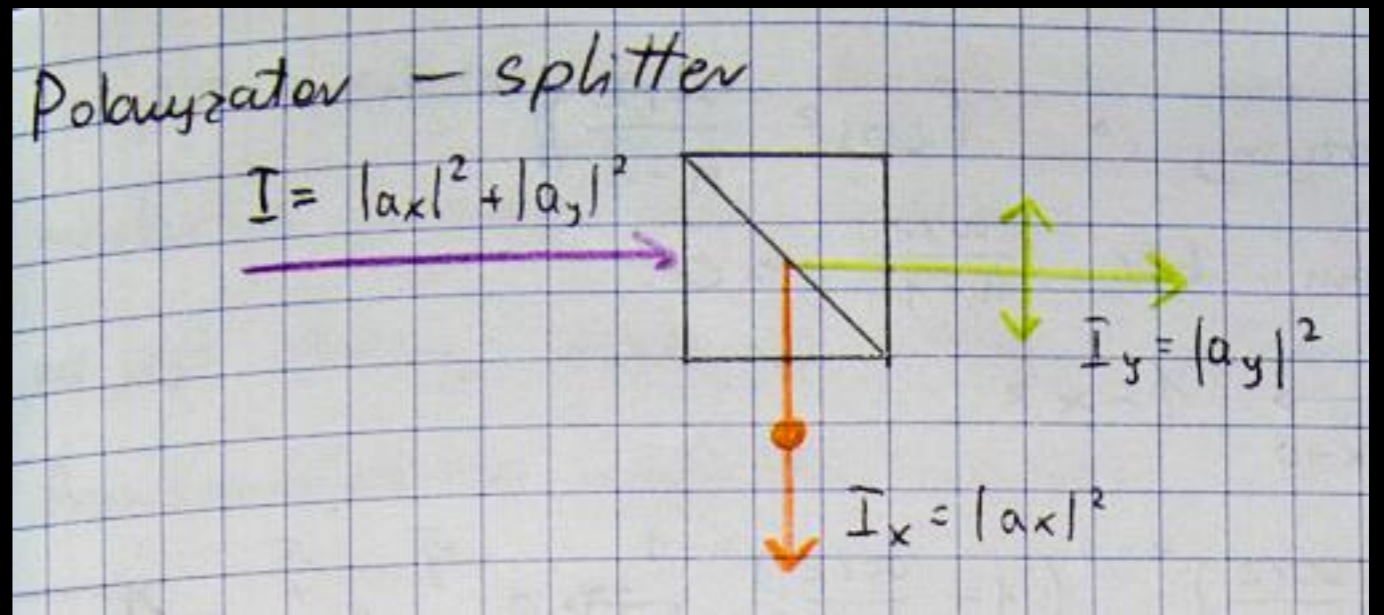
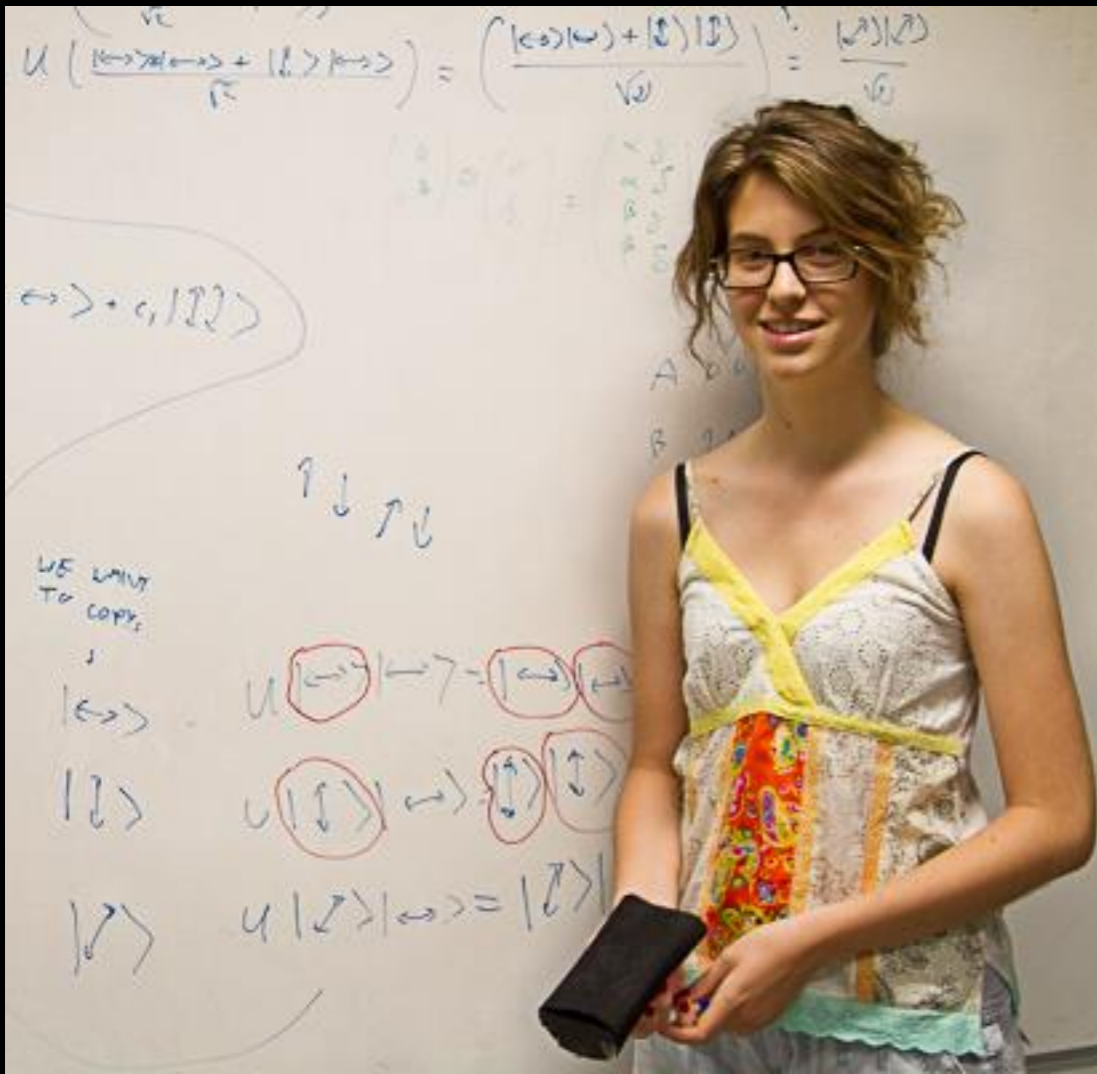
1 1 1
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Ponad tydzień warsztatów z matematyki, fizyki i informatyki, przygotowanych przez studentów dla licealistów, a poza tym wieczorne wykłady, gry planszowe i świetna atmosfera! ;)

Tematy z zeszłych lat:
Algebra Obliczeniowa, Zanurzenia Metryczne, Wizualizacja Danych, Szyfry Symetryczne, Ogólna Teoria Względności, Supernowe

Chętnych do wzięcia udziału albo do prowadzenia warsztatów zapraszamy na: warsztatywww.pl

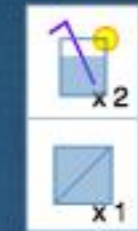
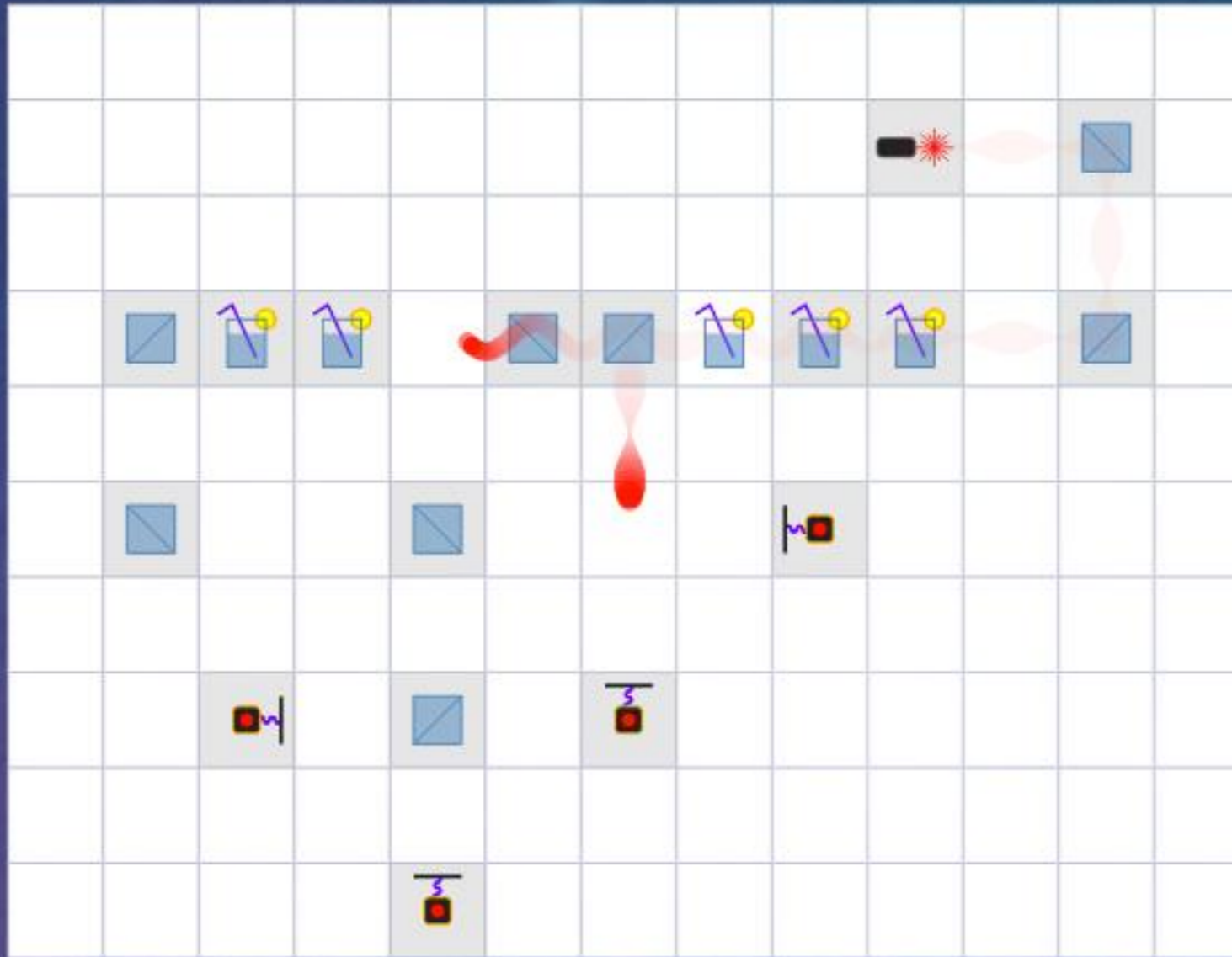




18

Polarizing beam splitter

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SUGAR SOLUTION

Table sugar is a chiral molecule – it does not look the same as its mirror reflection. We put it in an amount, so it rotates polarization by 45°.



0.0% (out of 100.0%) detection □ □ □ □ detectors

GOAL: Make the photon fall into 4 detectors, some probability to each, total of 100%.

beta version (3 Jun 2016)
by Piotr Migdał, Patryk Hes, Michał Krupiński

WE ARE TESTING
QUANTUM GAME
ON PEOPLE



PLANTS TOTALLY DON'T
GRASP THE INTERFACE

AND TESTING IT ON ANIMALS
WOULD BE UNETHICAL



...and PhD students
(this one is from Caltech)



A simple wish

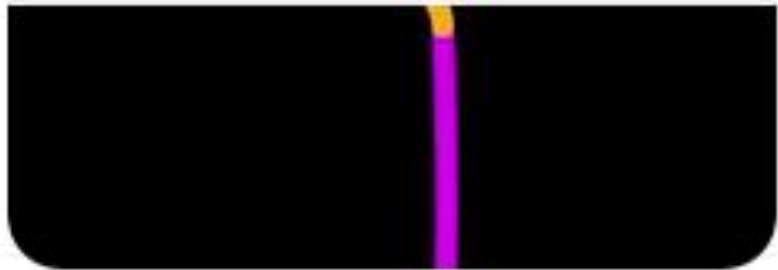
“All I want is the coolest quantum game in the known multiverse, please!”



5 people
late Aug - mid Nov 2019







Snake VS. Colors



Illu



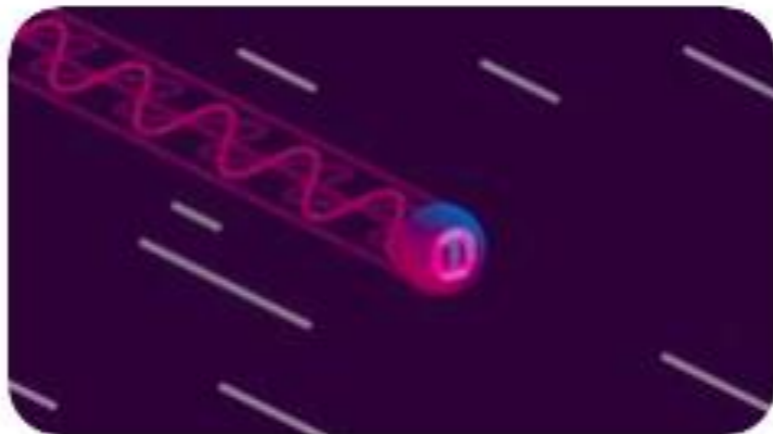
Dash Valley



Illu



The Last Star in the Universe
- Red Dwarfs...

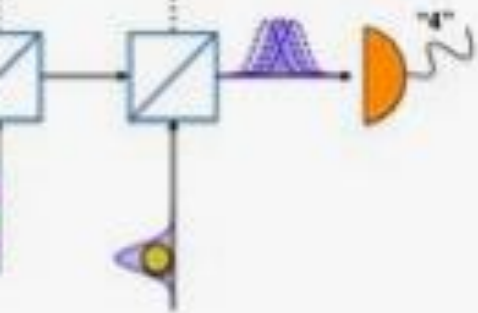


1920x1080 090_Website
Project QUANTUM...



Kurzges
YouTube





iment. Particles fall onto a can-
 am splitters with certain reflectiv-
 al combinatorial expectation for the
 icles in the detector is the product
 ities, e.g. $P_D(4\text{-fold coincidence}) =$
 ishable quantum particles, the re-

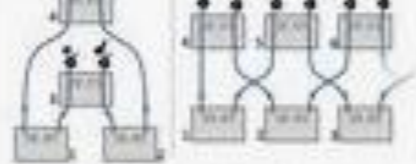


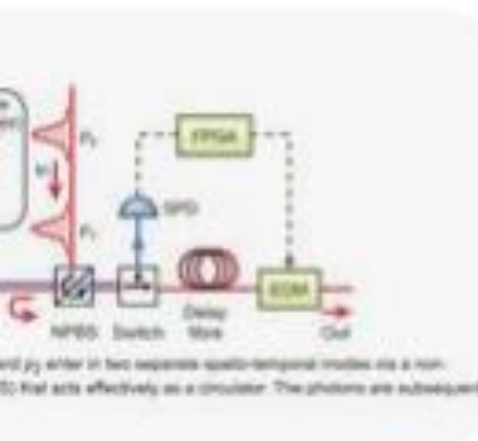
Figure 2. Multiphoton entanglement with polarizers. a. In two crystals, two photon pairs are produced. Crystal 1 and 2 produce horizontally polarized photons, while crystal 3 and 4 produce vertically polarized ones. Four-photon coincidences can only happen when crystal 1 and 2 fire together or when crystal 3 and 4 fire. This leads to a 4-particle GHZ-state $|\psi\rangle = \frac{1}{\sqrt{2}}(|H,H,H,H\rangle + |V,V,V,V\rangle)$. b. Entangled states with more numbers of particles can be created in an analogous way. Here a 6-photon GHZ state $|\psi\rangle = \frac{1}{\sqrt{2}}(|H,H,H,H,H,H\rangle + |V,V,V,V,V,V\rangle)$ is shown.

photon coincidences. For example, if the pairs are
 produced in crystal 1 & 3, there will be two photons

Entanglement by Path Identity by Zeilinger 2



Figure 3. W-state with an $|\psi\rangle = \frac{1}{\sqrt{3}}(|CVMM\rangle + |MVWM\rangle + |WVVM\rangle + |MMVV\rangle)$ represents a different type of multi-photon entanglement. While the GHZ state is considered as the most non-classical state, a W-state is the most robust entangled state because the loss of one particle leaves an entangled state. Here, four-photon coincidences can only happen if crystal 1 & 2 produce both a pair of photons, or crystal 3 & 4, or crystal 1 & 3 or 2 & 4. Interestingly, in this setup, one photon from crystal 1 can stimulate an emission in crystal 3. However, this will not lead to four-photon coincidences, as there is no photon in path 3. Thus, this event can be neglected.



4-photon gate

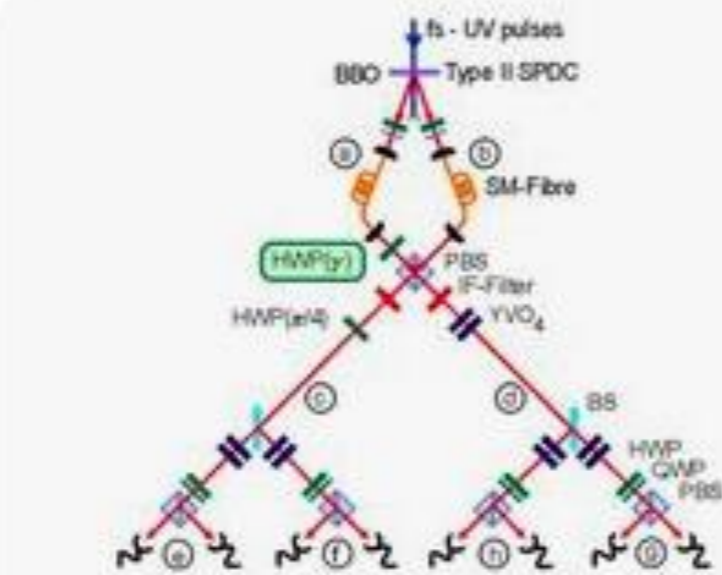


FIG. 1: Schematic experimental set-up for the observation of the family $|\Psi(\gamma)\rangle$. For details see text.

8 detectors setup

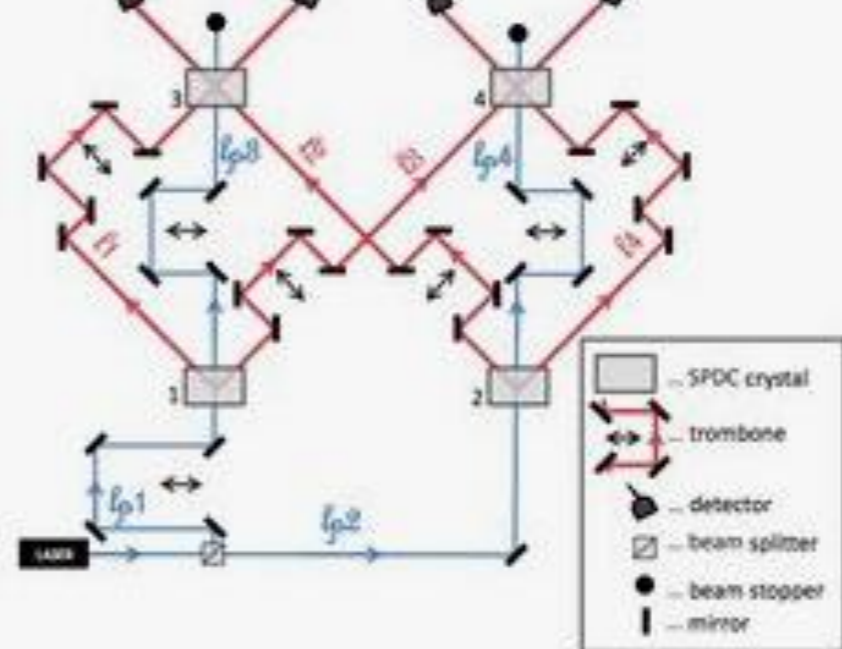


Figure 5. A realistic diagram of the experiment described in the main text, which produces a 4-photon GHZ-state in polarization. The pump length ℓ_{p1} and ℓ_{p2} start at the BS and end at crystals 1 and 2. The lengths ℓ_{p3} and ℓ_{p4} start at crystals 1 and 2, and end at crystals 3 and 4. The lengths for the down-conversion photons ℓ_i start at the crystals 1 and 2, and end at crystals 3 and 4.

Entanglement by Path Identity, Zeilinger

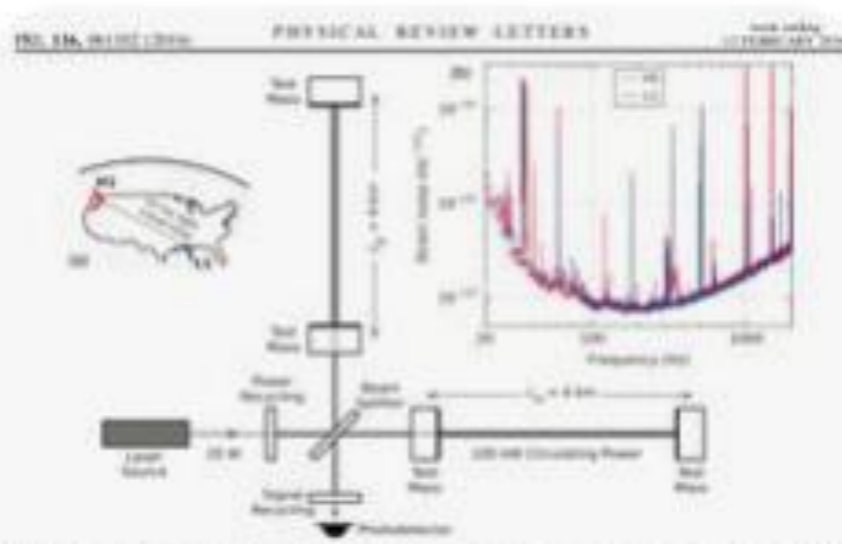


FIG. 1. Schematic diagram of a LIGO interferometer with a spectrum plot showing frequency components.

LIGO interferometer



Fig. 1. (color online). The schematic of a four-photon GHZ state.

More complicated



FIG. 1: (color online) Schematic diagram of a linear optical setup with UV enhancement.

Dicke state generation

Explorable explanations

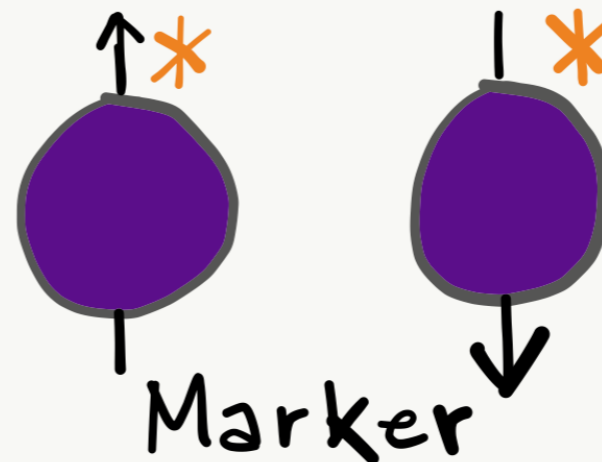
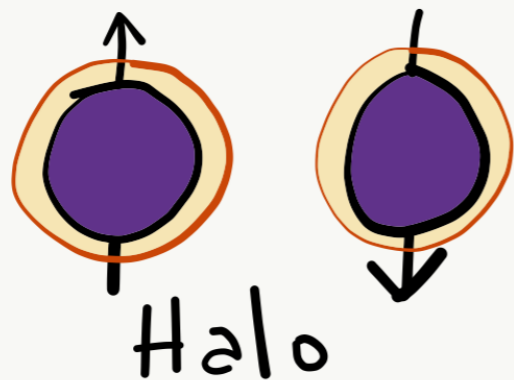
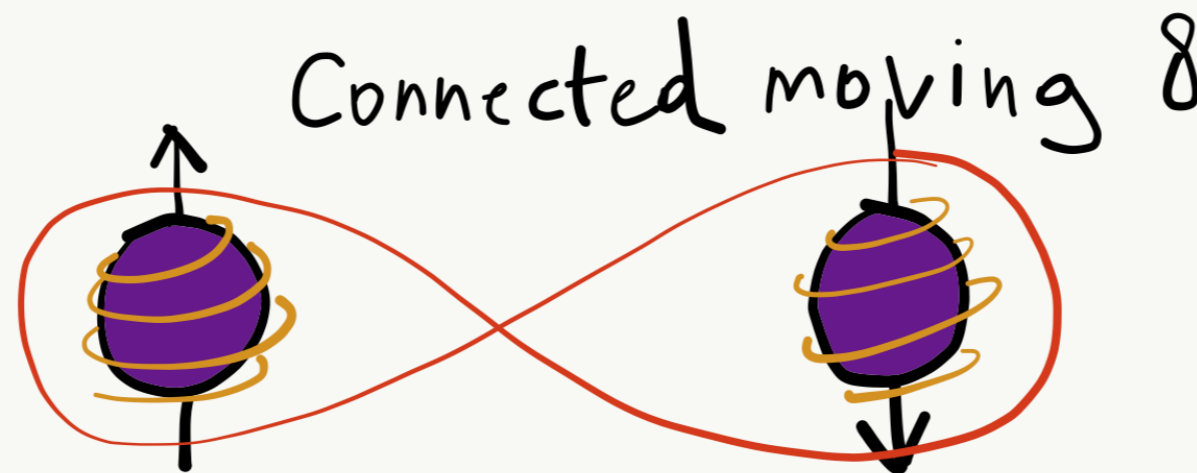
$$X_k = \frac{1}{N} \sum_{n=0}^{N-1} x_n e^{i2\pi k \frac{n}{N}}$$

To find the energy at a particular frequency, spin your signal around a circle at that frequency, and average a bunch of points along that path.

Concept art

by Chiara Decaroli

Entanglement I - Electrons

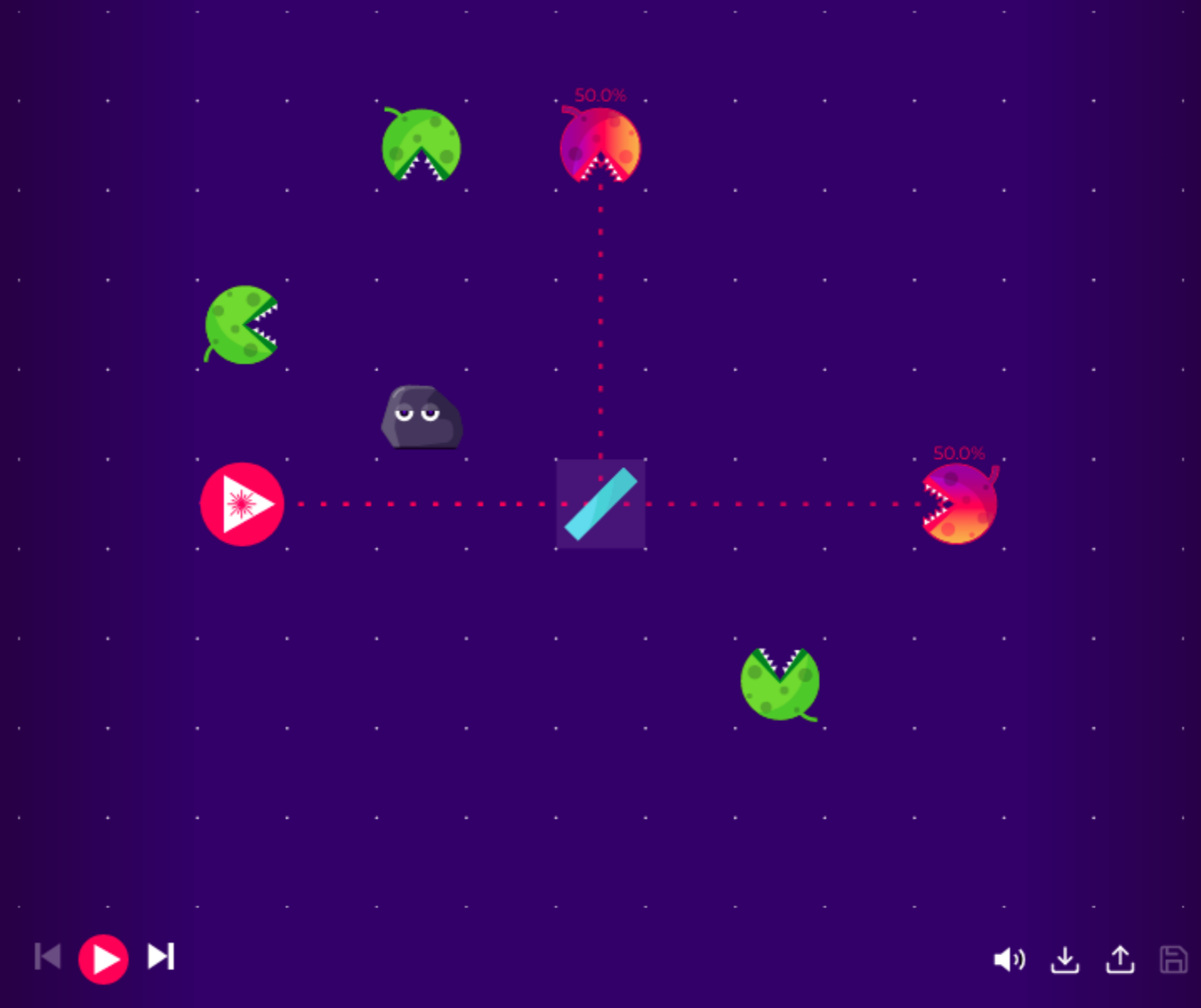
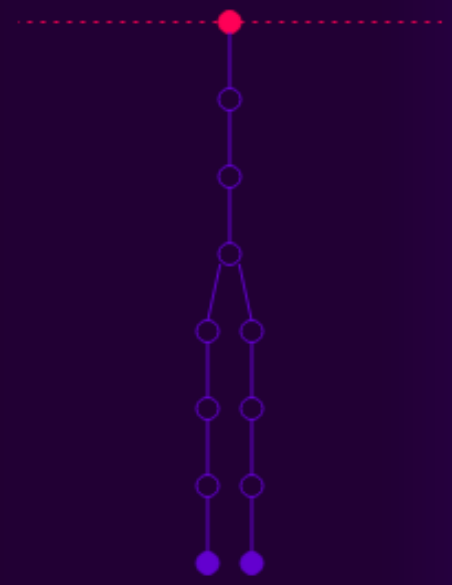




2 - DIVIDE AND CONQUER!

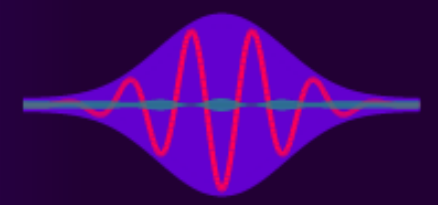


Goal: 87.5 %



3 (4)

PHOTON



Ket: $(1.00 + 0.00i) | \rightarrow H \rangle$

POLAR CARTESIAN COLOR

$1.00 \exp(i0.00) | 2,5 \rightarrow H \rangle$

amplitude (complex number) x,y
coordinates direction polarization

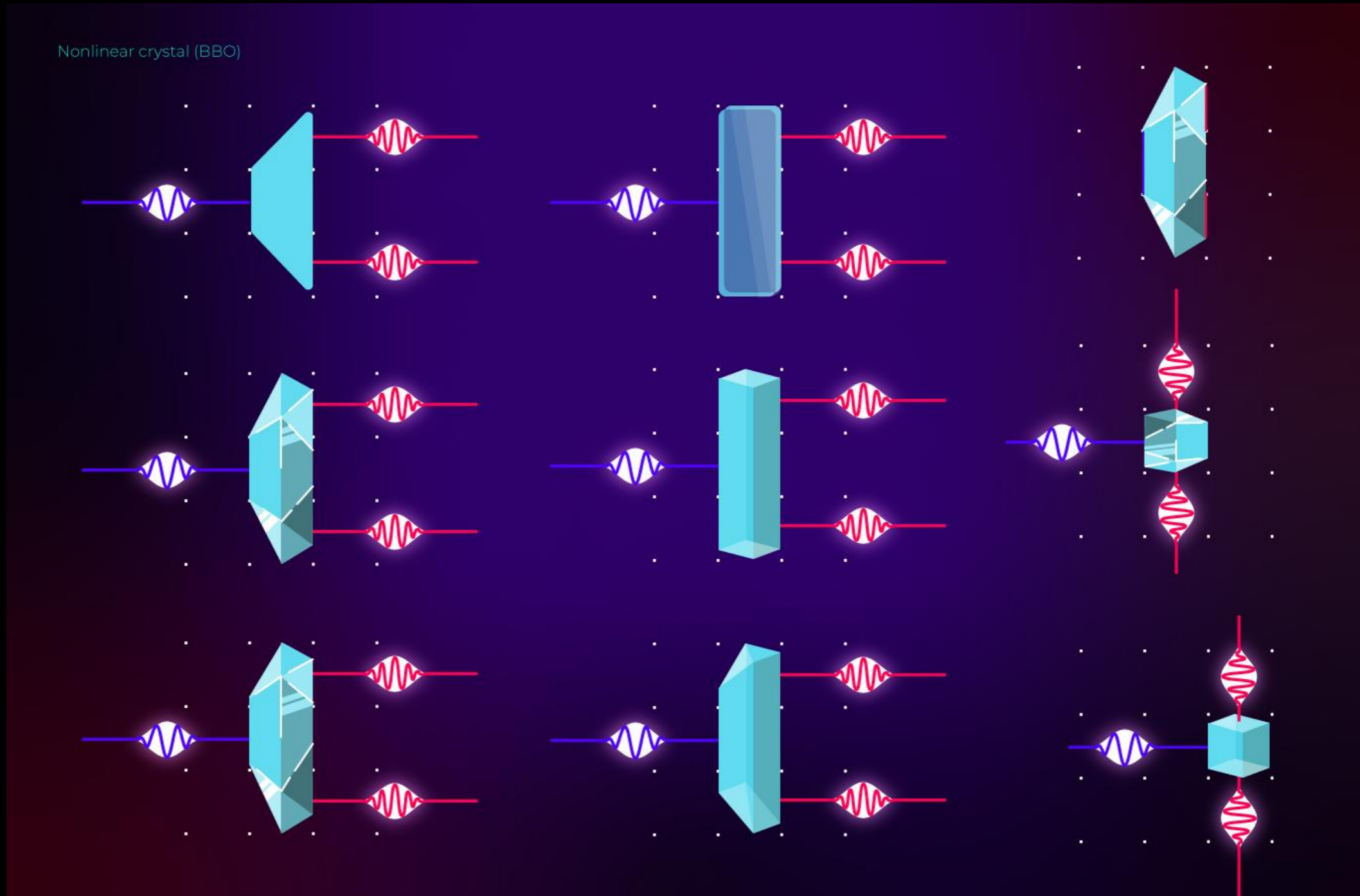


<https://alpha.quantumgame.io>
<http://localhost:8080/>

What's next?

- BIG idea:
more particles, entanglement, quantum key distribution (Ekert protocol!), quantum teleportation, Everett's many-worlds interpretation
- BIGGER idea:
an interactive textbook teaching quantum information!

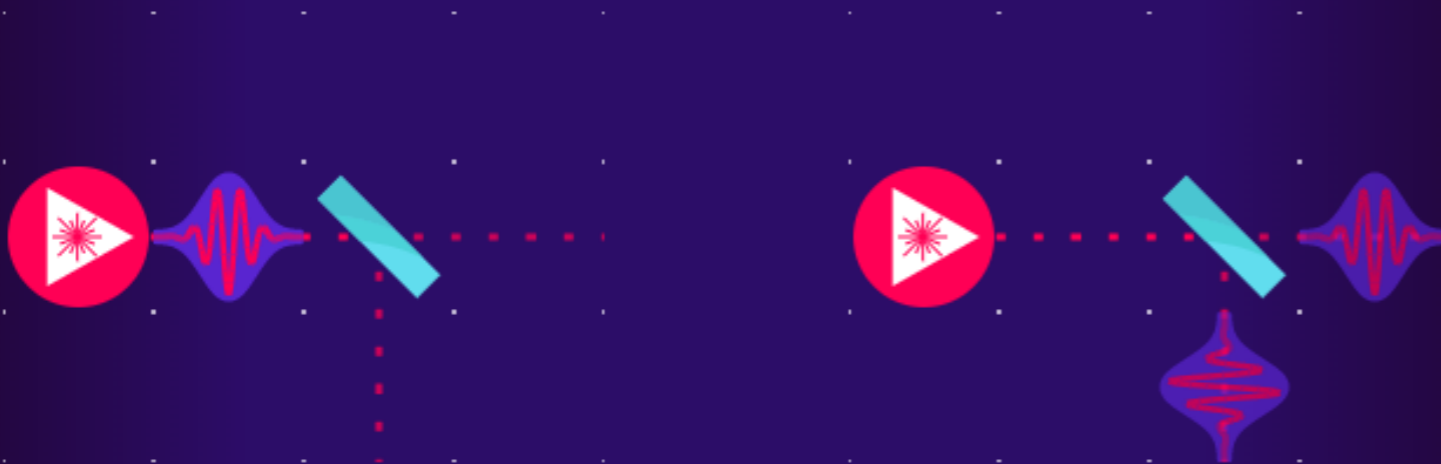
Parametric downconversion



Interactive data

50-50 BEAMSPLITTER

Optical devices used to split a single beam of laser light into two beams, or to recombine two beams into one.



POLAR CARTESIAN COLOR

$1.00 \exp(i0.00)$ $|1,1 \rightarrow H\rangle$

POLAR CARTESIAN COLOR

$0.71 \exp(i0.00)$ $|3,1 \rightarrow H\rangle$

$0.71 \exp(i4.71)$ $|2,2 \downarrow H\rangle$

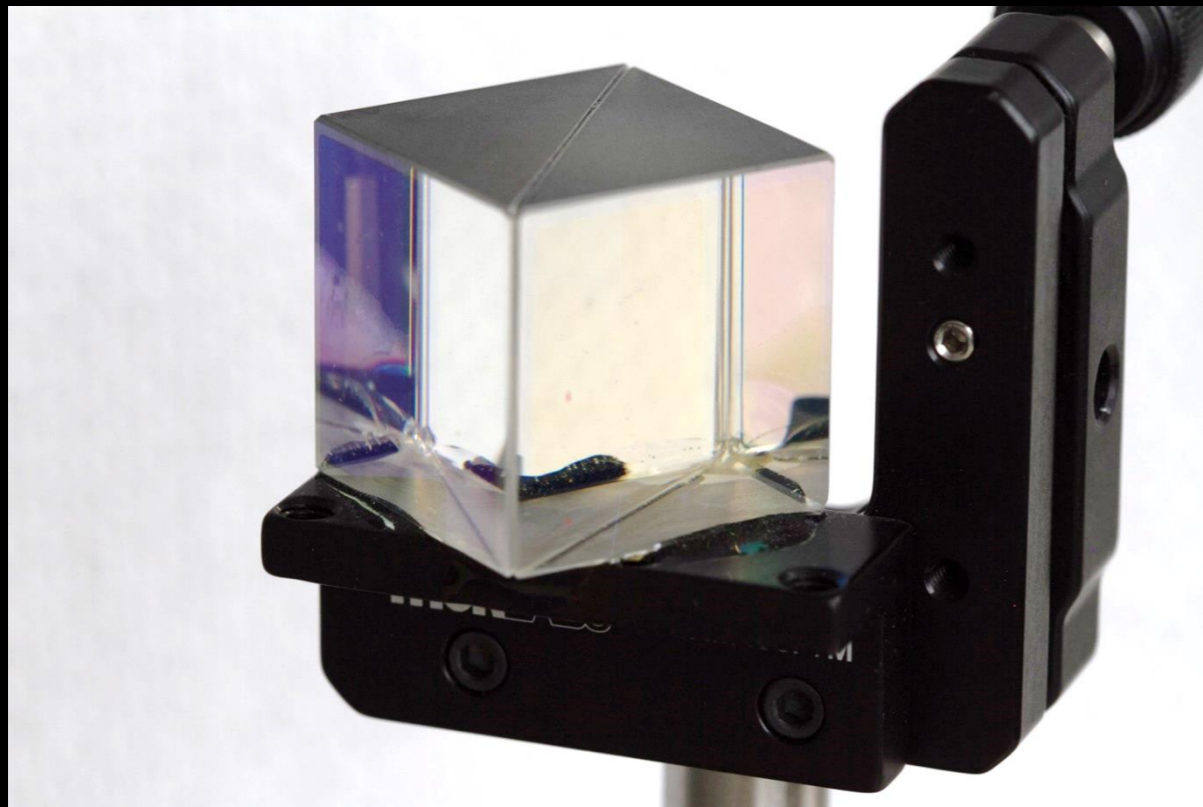
99 lines (75 sloc) | 4.47 KB

50-50 Beamsplitter

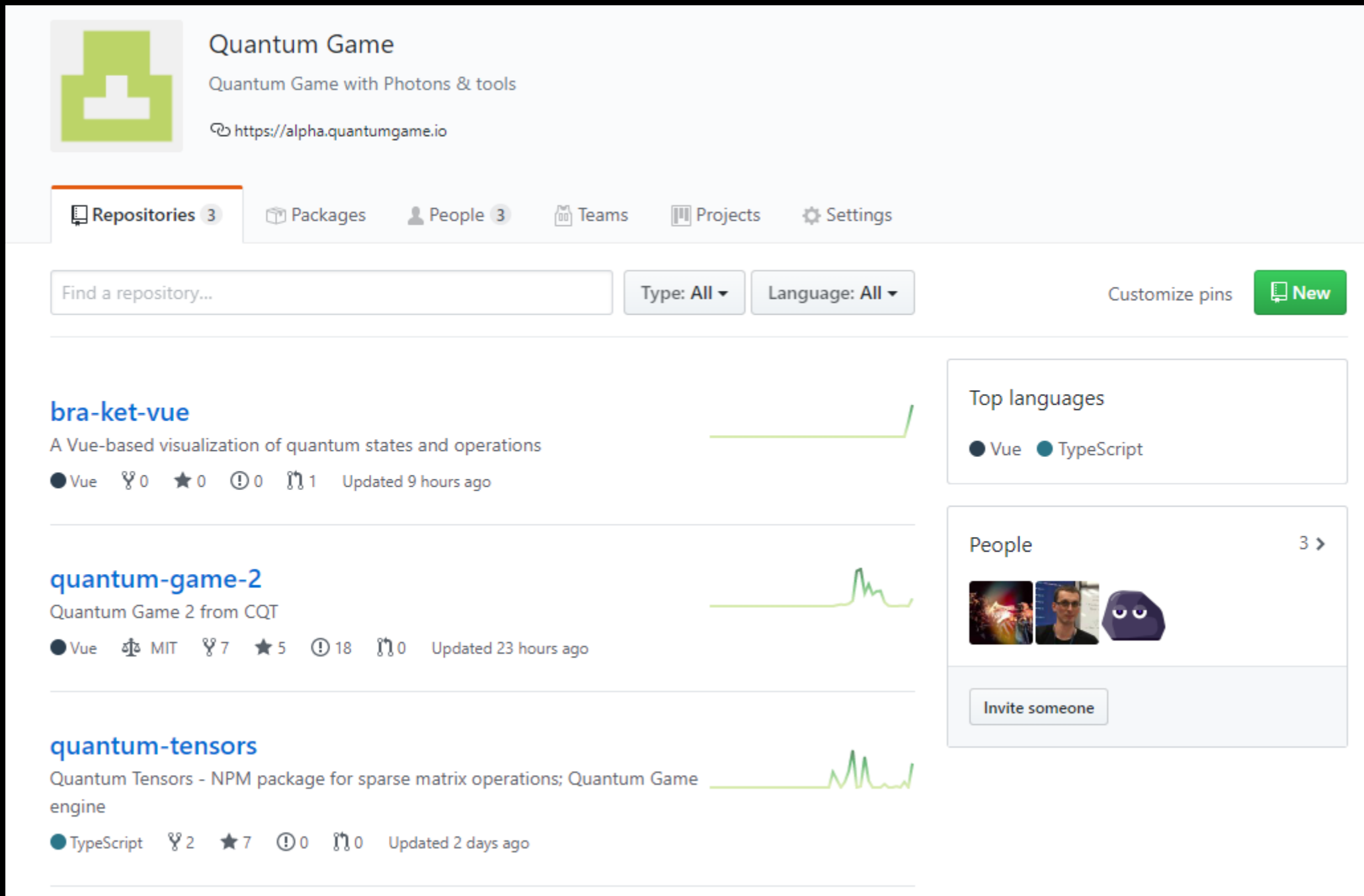
Optical devices used to split a single beam of laser

```
{
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  "rows": 3,
  "cells": [
    {
      "coord": { "y": 0, "x": 0 },
      "element": "Laser",
      "rotation": 0,
      "frozen": true,
      "active": true
    },
    {
      "coord": { "y": 0, "x": 2 },
      "element": "BeamSplitter",
      "rotation": 135,
      "frozen": false,
      "active": false
    }
  ]
}
```

Connection to a real lab



The project



The screenshot shows the GitHub repository page for 'Quantum Game'. The repository is owned by 'Quantum Game' and is described as 'Quantum Game with Photons & tools'. The URL is 'https://alpha.quantumgame.io'. The page features a navigation bar with 'Repositories 3', 'Packages', 'People 3', 'Teams', 'Projects', and 'Settings'. Below the navigation bar is a search bar for repositories, filters for 'Type: All' and 'Language: All', and buttons for 'Customize pins' and 'New'. The main content area displays three repository cards: 'bra-ket-vue', 'quantum-game-2', and 'quantum-tensors'. Each card includes the repository name, a description, a language indicator, and various statistics (forks, stars, issues, pull requests) along with a commit history graph. The right sidebar shows 'Top languages' (Vue, TypeScript) and 'People' (3 contributors) with an 'Invite someone' button.

Quantum Game
Quantum Game with Photons & tools
<https://alpha.quantumgame.io>

Repositories 3 Packages People 3 Teams Projects Settings

Find a repository... Type: All Language: All Customize pins New

bra-ket-vue
A Vue-based visualization of quantum states and operations
● Vue 0 forks 0 stars 0 issues 1 pull request Updated 9 hours ago

quantum-game-2
Quantum Game 2 from CQT
● Vue MIT 7 forks 5 stars 18 issues 0 pull requests Updated 23 hours ago

quantum-tensors
Quantum Tensors - NPM package for sparse matrix operations; Quantum Game engine
● TypeScript 2 forks 7 stars 0 issues 0 pull requests Updated 2 days ago

Top languages
● Vue ● TypeScript

People 3 >
Invite someone



Piotr Migdal
@pmigdal



I am now in a loving & safe relationship with TypeScript!

My relationship with pure JavaScript is, well, undefined...

11:39 AM · Oct 2, 2019 · [Twitter Web App](#)

- TypeScript – the sane JavaScript
- Vue.js – for its modularity & simplicity
- ESLint as our strict, grammar-policeman
- JSON / Markdown / stuff
- Merges, squash rebases, whatever works...

QUANTUM TENSORS

- open source, TypeScript library for interactive quantum: information, computing, optics, etc!

```
Creating Photon
```

```
(0.71 +0.00i) |0,2,>,H,2,0,v,H) + (0.71 +0.00i) |2,0,v,H,0,2,>,H)
```

```
Steps:
```

```
Step 0: (0.71 +0.00i) |1,2,>,H,2,1,v,H) + (0.71 +0.00i) |2,1,v,H,1,2,>,H)
```

```
Step 1: (0.00 -0.71i) |2,2,>,H,2,2,>,H) + (0.00 -0.71i) |2,2,v,H,2,2,v,H)
```

```
Step 2: (0.00 -0.71i) |3,2,>,H,3,2,>,H) + (0.00 -0.71i) |2,3,v,H,2,3,v,H)
```

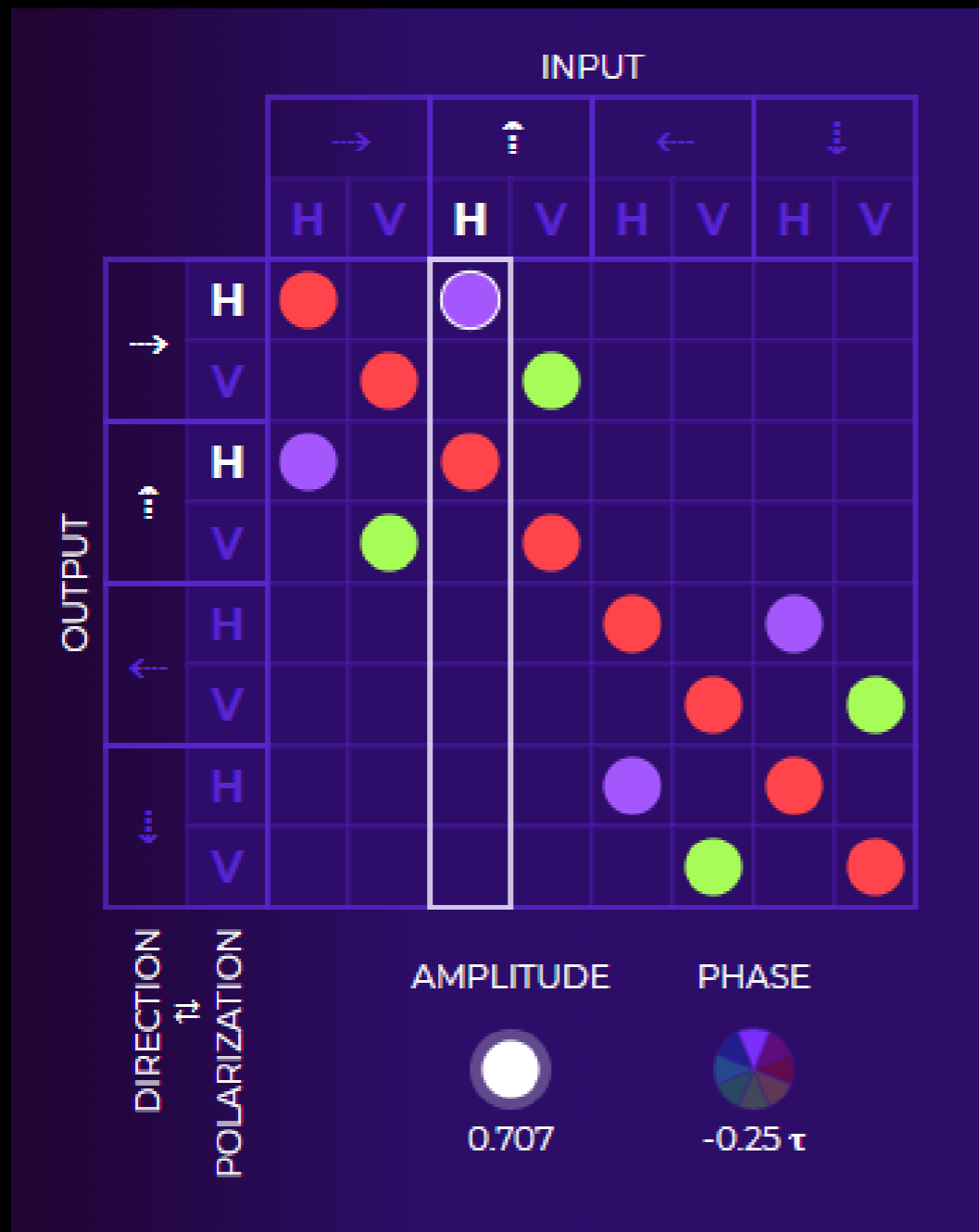
```
Step 3: (0.00 -0.71i) |4,2,>,H,4,2,>,H) + (0.00 -0.71i) |2,4,v,H,2,4,v,H)
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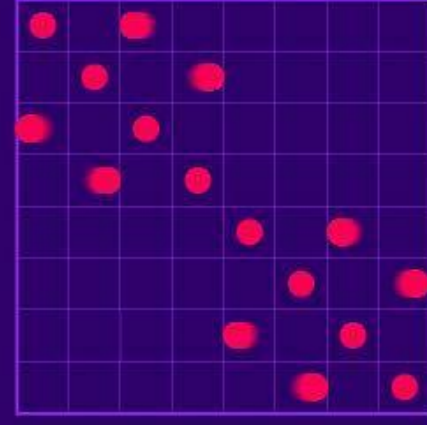
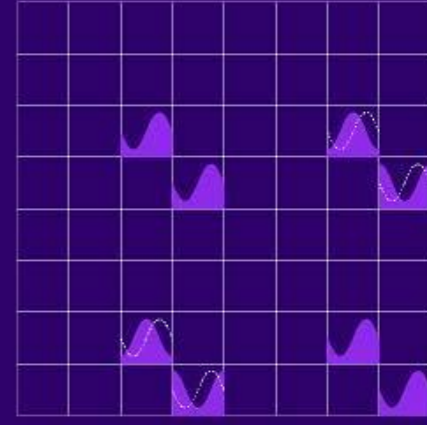
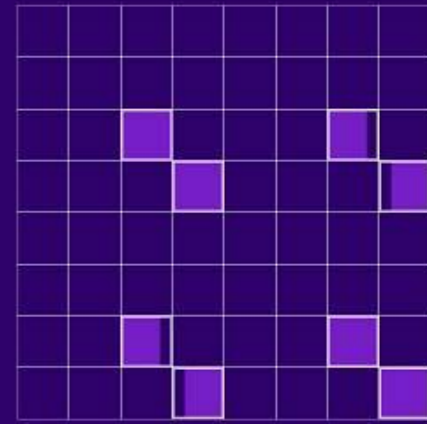
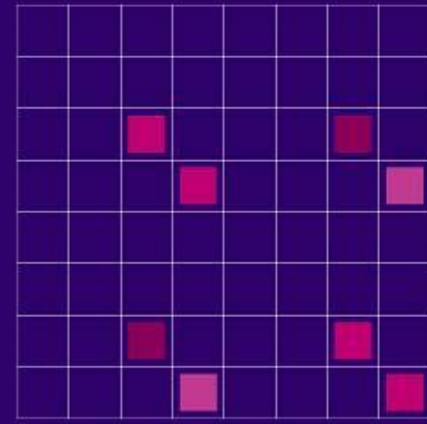
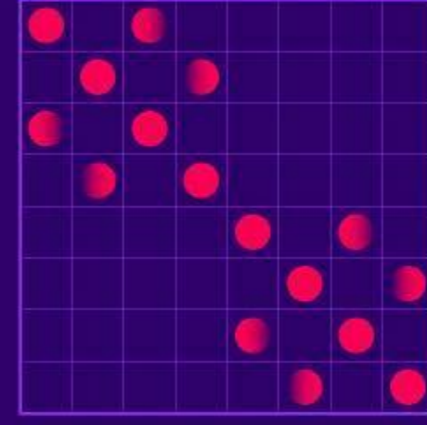
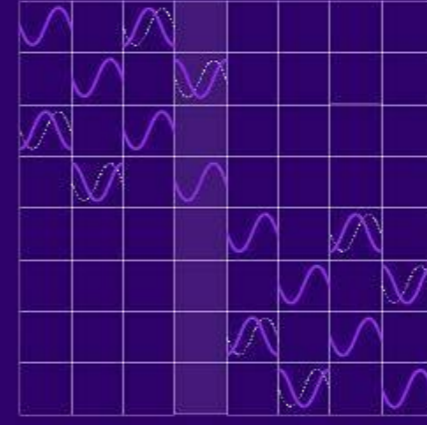
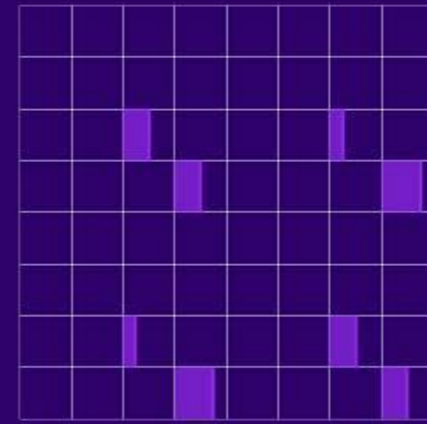
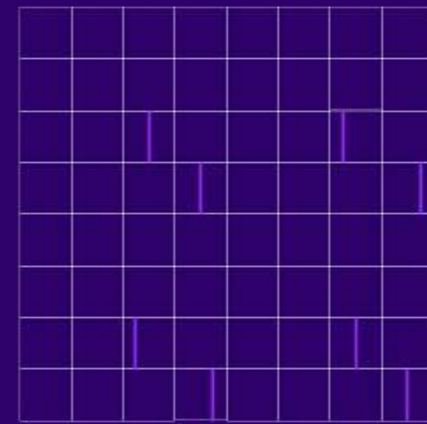
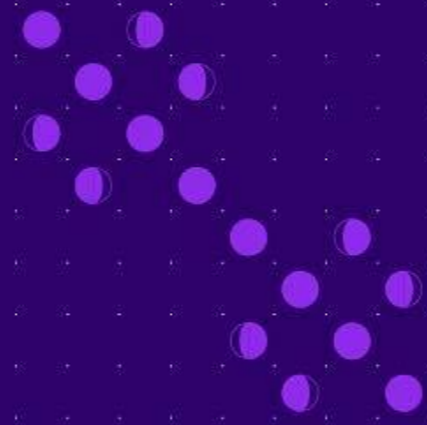
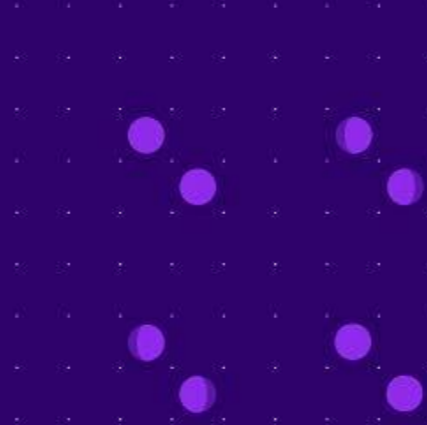
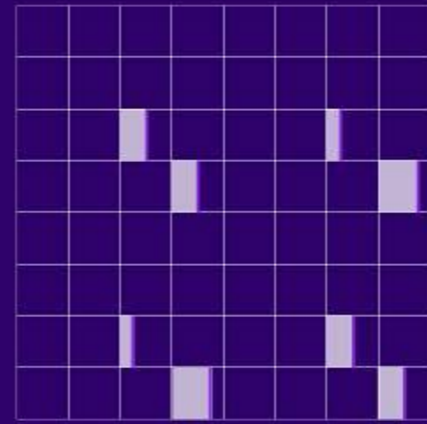
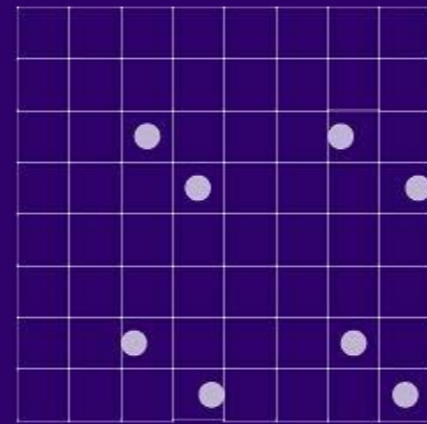
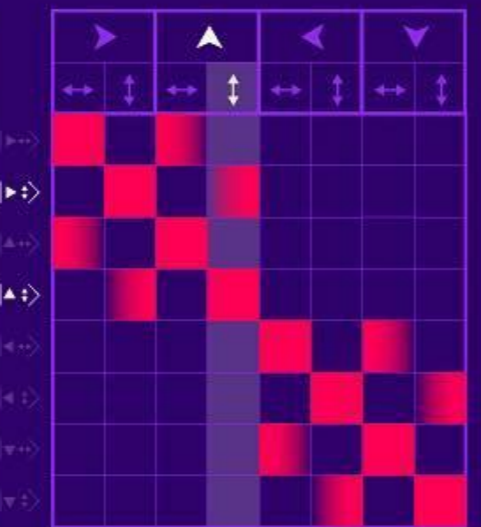
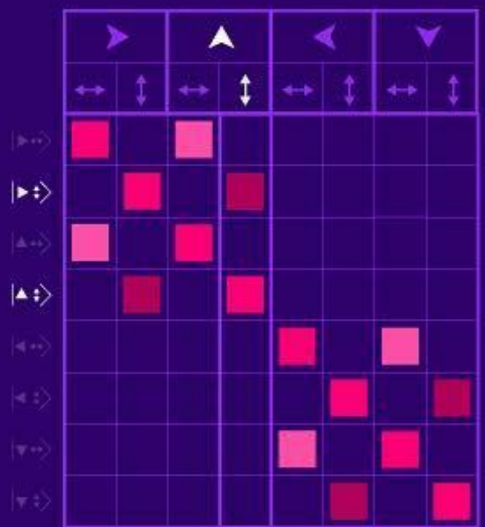
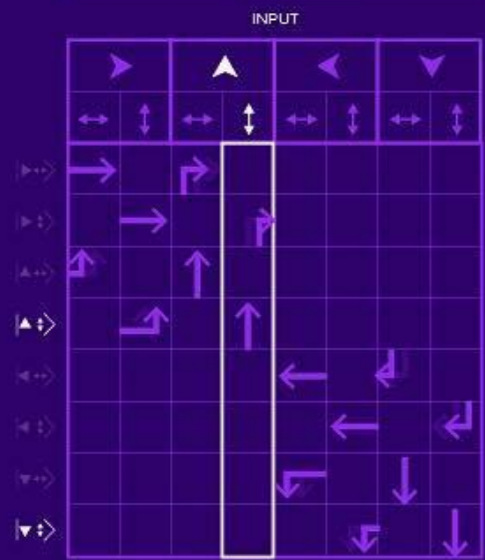
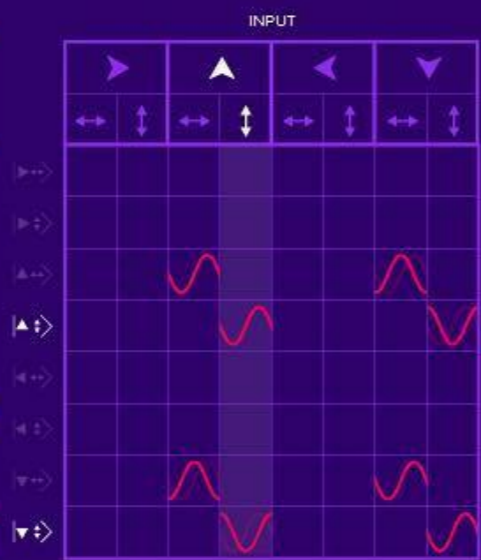
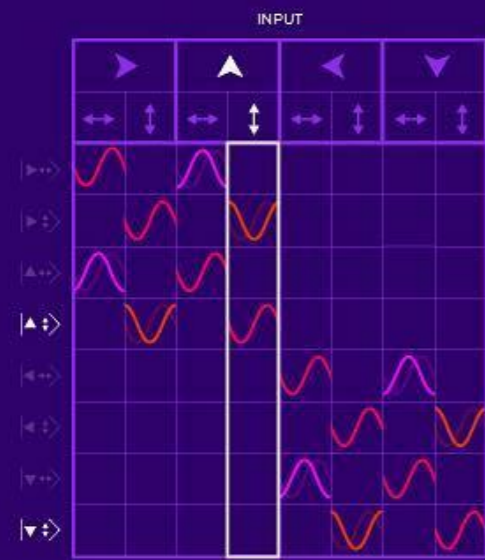
```
Step 4: (0.00 -0.71i) |5,2,>,H,5,2,>,H) + (0.00 -0.71i) |2,5,v,H,2,5,v,H)
```

```
Step 5: (0.00 -0.71i) |6,2,>,H,6,2,>,H) + (0.00 -0.71i) |2,6,v,H,2,6,v,H)
```

<https://github.com/Quantum-Game/quantum-tensors>

Components for... (v)you!



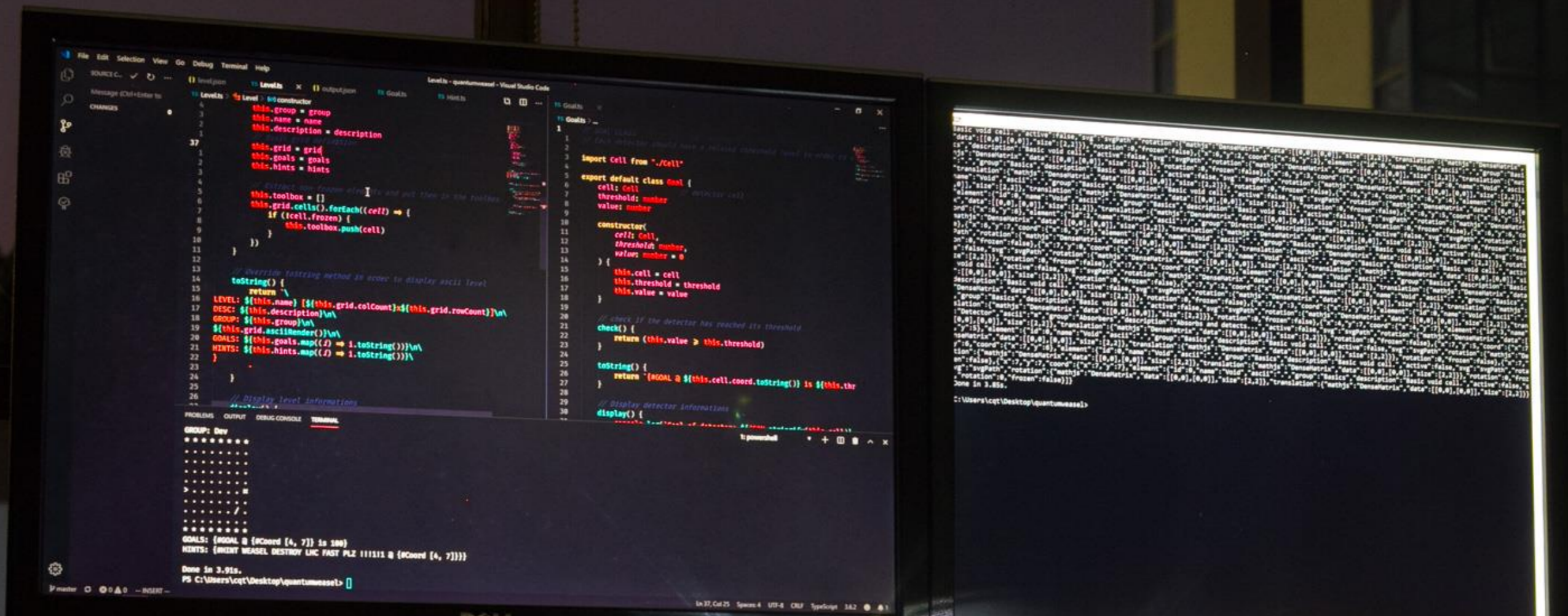


select polarization basis



select dimension order





Work in progress...

Thank you!

- Follow us:
twitter.com/QuantumGameIO
github.com/Quantum-Game
- Play alpha version:
alpha.quantumgame.io
- Interested in collaboration? :)
Programming (numerics, frontend),
level design, writing (encyclopedia)
pmigdal@gmail.com / p.migdal.pl



+Kuba Strebeyko, Pawel Janicki

Additional slides



Piotr Migdał

June 23 · Warsaw · 🌐 ▼

Hyperbolic geometry + an indie roguelike = a geeky (LSD) trip into different dimensions. Yes, R'lyeh is there as well.

<http://www.roguetemple.com/z/hyper/>

HN: <https://news.ycombinator.com/item?id=9744353>



HyperRogue 4.0

HyperRogue 4.0 To see all the 11 lands and complete the quest for Orbs of Yendor, download the game at: <http://roguetemple.com/z/hyper.php>

YOUTUBE.COM

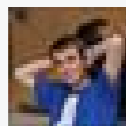
16 Likes 8 Comments

👍 Like

💬 Comment

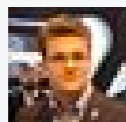
➦ Share

Paweł Schreiber,



Piotr Migdał

June 23 at 6:11pm



Jan K. Marucha Mam wrażenie, że spędzasz życie na szukanie po internetach sposobu, by oszczędzić na narkotykach.

June 23 at 6:11pm · Like · 👍 7

I think that you are searching the Internet to save on drugs.

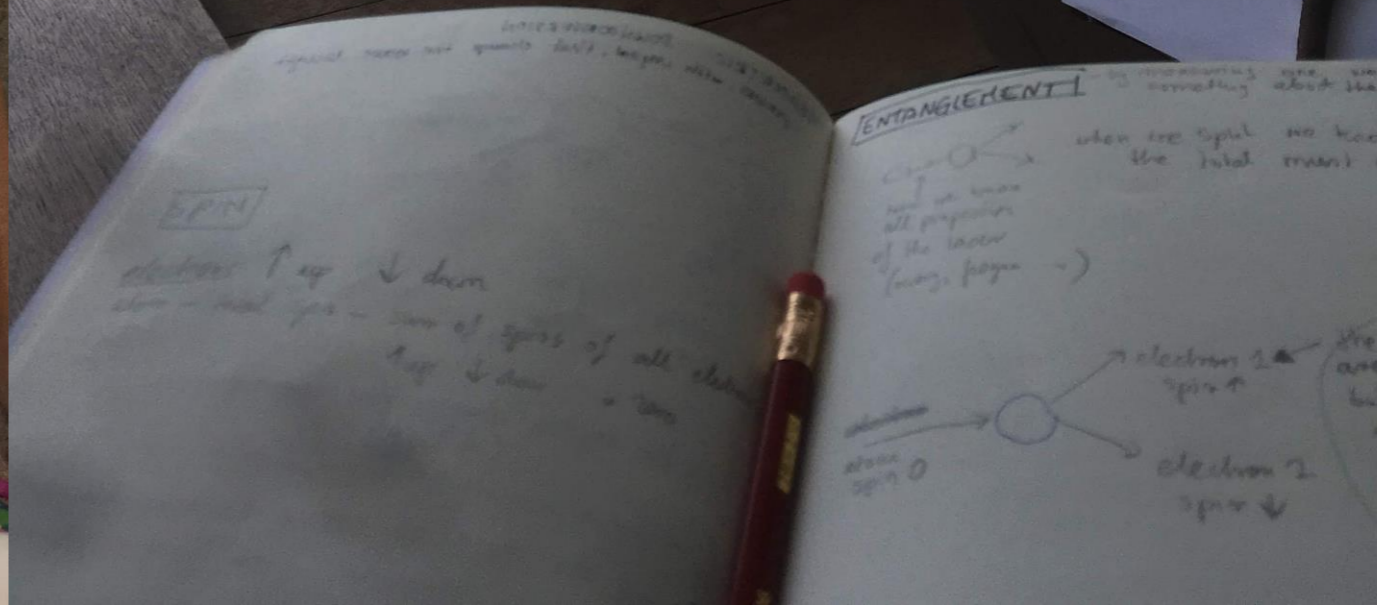
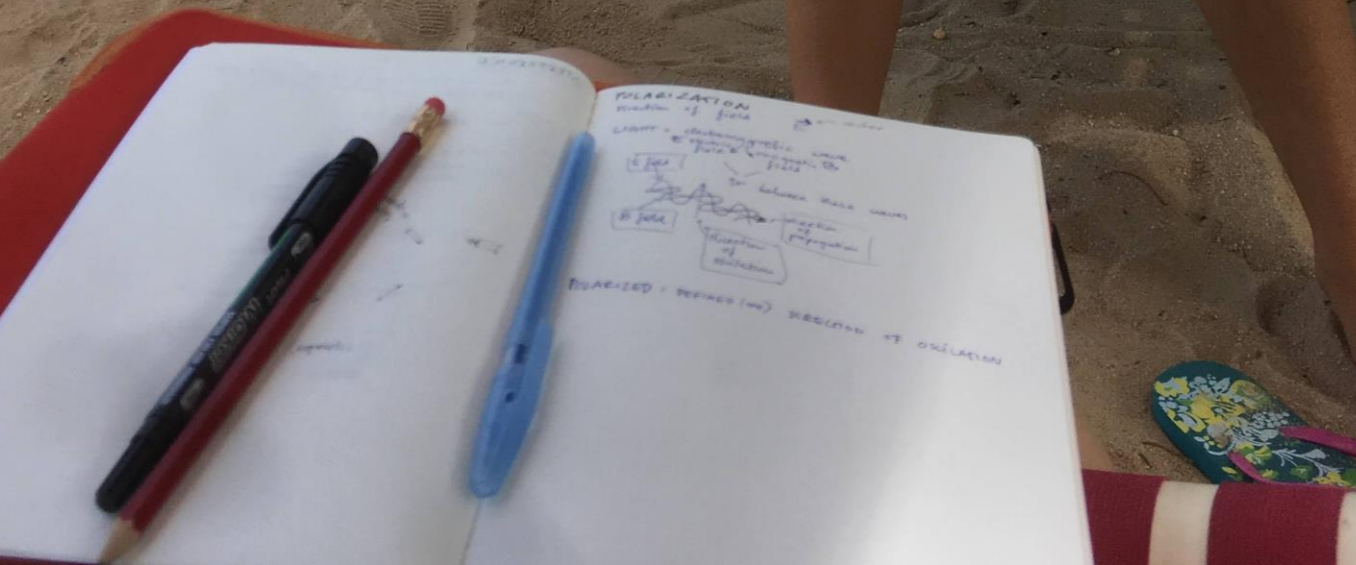
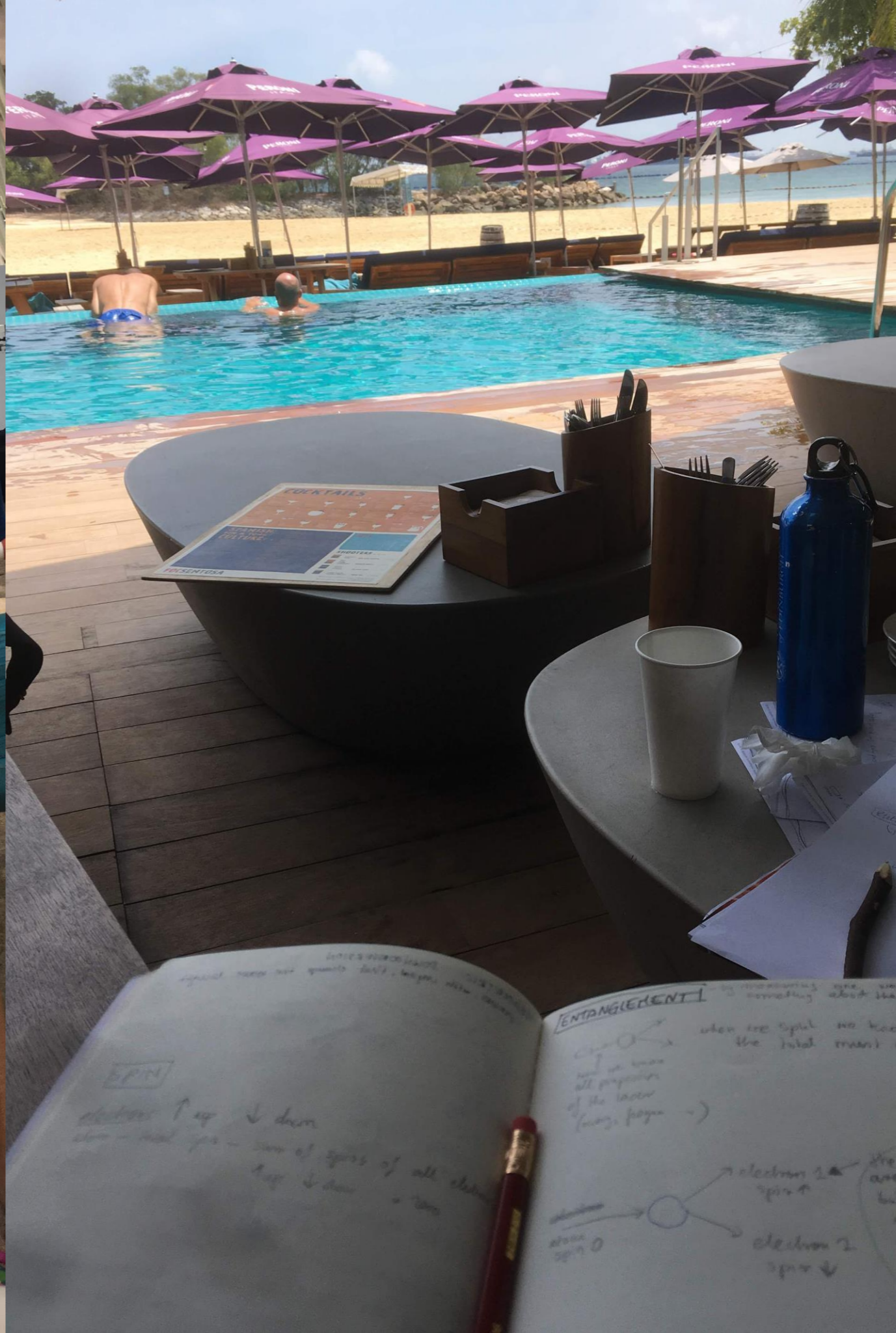
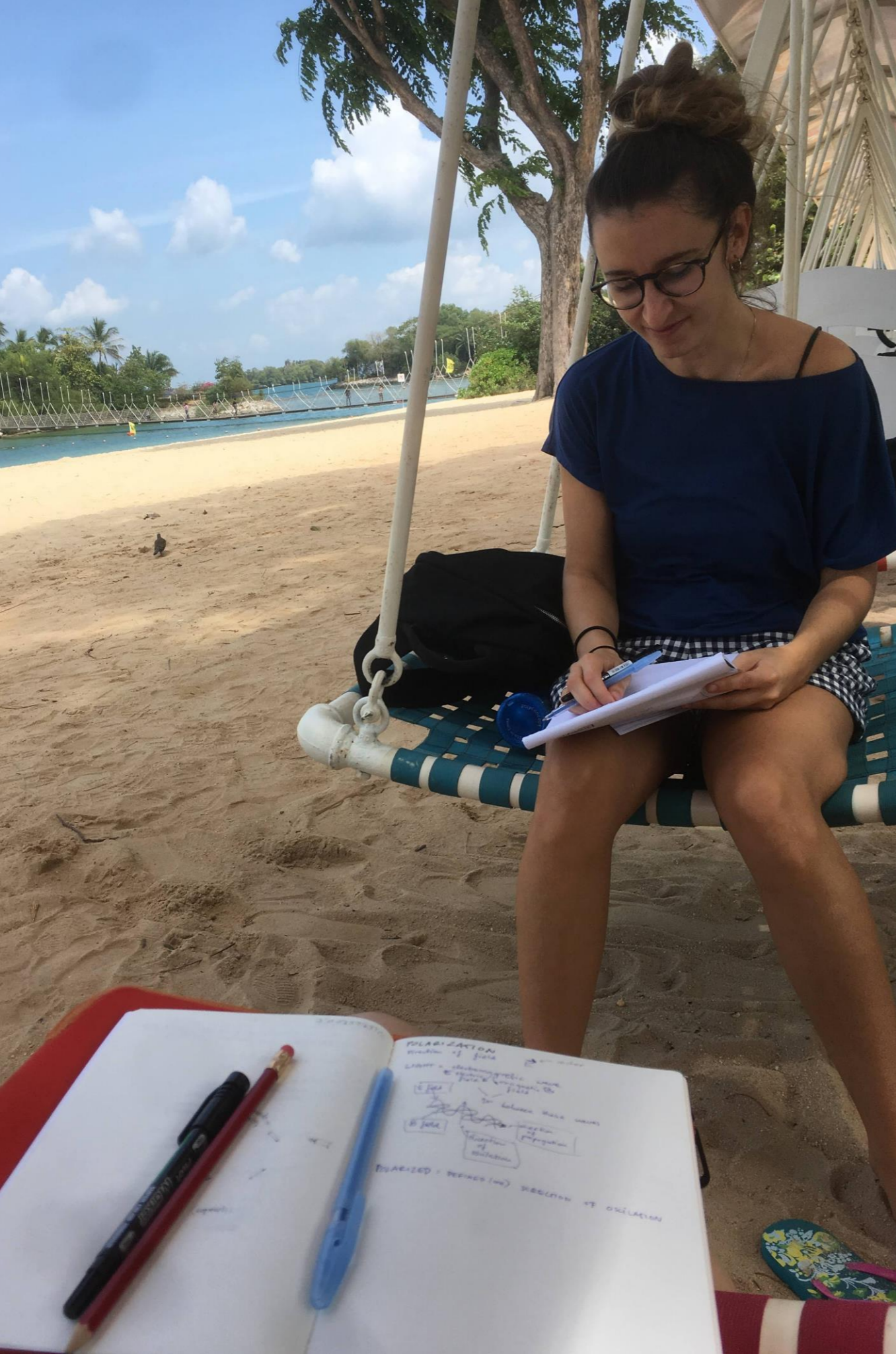
More!

- <https://github.com/stared/science-based-games-list>

≡ **science-based-games-list**

Science-based games - a collaborative list

★ 1.1k 🍴 61



Lessons learn

- Hiring a whole team of creative people is hard
- There is no such thing as „a game on time”
- Collaboration between various people is fruitful...
- ...at the same: constant overflow of ideas
- Being a manager, creative lead, and software engineer within the same day is a bit too much...