J. Opt. **24** (2022) 015701 (10pp) https://doi.org/10.1088/2040-8986/ac3a9e

An optical processor for matrix-by-vector multiplication: an application to the distance geometry problem in 1D

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IOP Publishing
Journal of Optics
J. Opt. 24 (2022) 015701 (10pp)
https://doi.org/10.1088/2040-8986/ac3a9e

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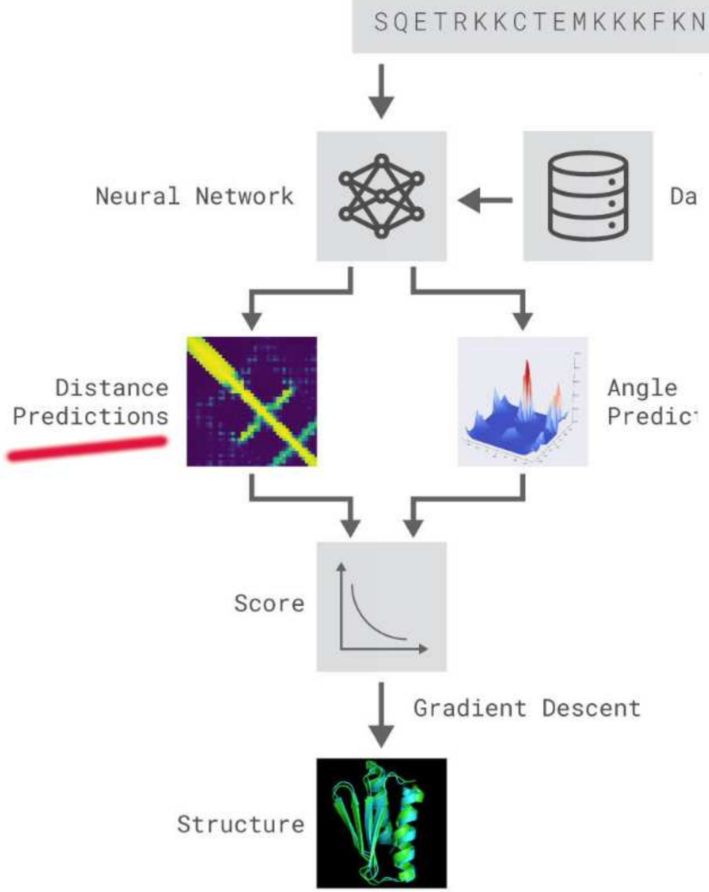

nature
https://doi.org/10.1038/s41586-021-03819-2
Accelerated Article Preview

Highly accurate protein structure prediction with AlphaFold

Received: 11 May 2021

Accepted: 12 July 2021

Accelerated Article Preview Published online 15 July 2021

Cite this article as: Jumper, J. et al. Highly accurate protein structure prediction with AlphaFold. *Nature* https://doi.org/10.1038/s41586-021-03819-2 (2021).

John Jumper, Richard Evans, Alexander Pritzel, Tim Green, Michael Figurnov, Olaf Ronneberger, Kathryn Tunyasuvunakool, Russ Bates, Augustin Žídek, Anna Potapenko, Alex Bridgland, Clemens Meyer, Simon A. A. Kohl, Andrew J. Ballard, Andrew Cowie, Bernardino Romera-Paredes, Stanislav Nikolov, Rishub Jain, Jonas Adler, Trevor Back, Stig Petersen, David Reiman, Ellen Clancy, Michal Zielinski, Martin Steinegger, Michalina Pacholska, Tamas Berghammer, Sebastian Bodenstein, David Silver, Oriol Vinyals, Andrew W. Senior, Koray Kavukcuoglu, Pushmeet Kohli & Demis Hassabis

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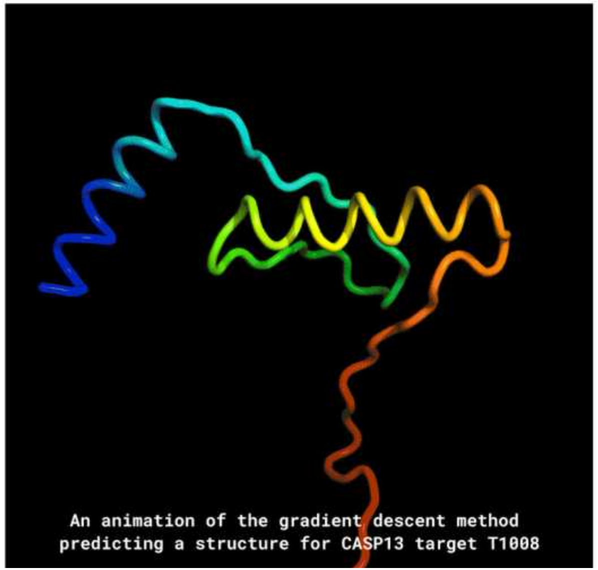


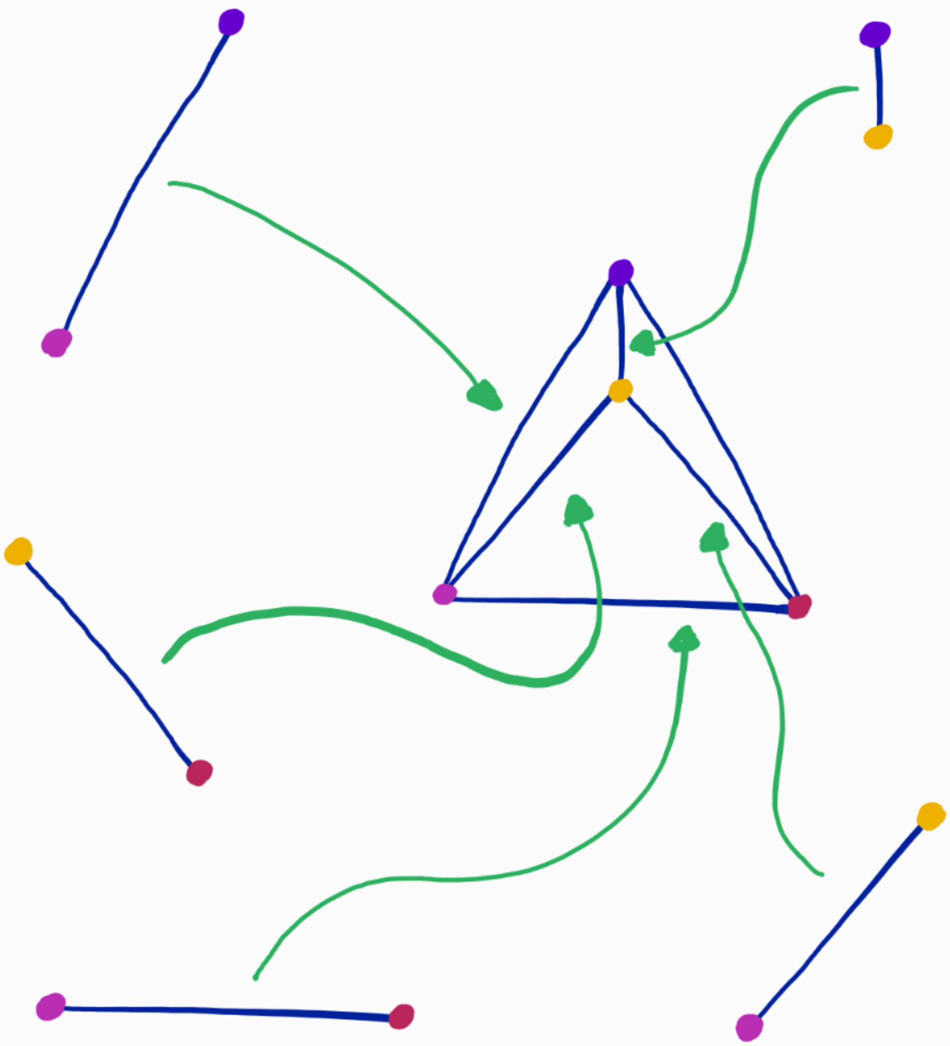
RESEARCH ARTICLE

PROTEIN FOLDING

Accurate prediction of protein structures and interactions using a three-track neural network

Minkyung Baek[1,2], Frank DiMaio[1,2], Ivan Anishchenko[1,2], Justas Dauparas[1,2], Sergey Ovchinnikov[3,4], Gyu Rie Lee[1,2], Jue Wang[1,2], Qian Cong[5,6], Lisa N. Kinch[7], R. Dustin Schaeffer[6], Claudia Millán[8], Hahnbeom Park[1,2], Carson Adams[1,2], Caleb R. Glassman[9,10,11], Andy DeGiovanni[12], Jose H. Pereira[12], Andria V. Rodrigues[12], Alberdina A. van Dijk[13], Ana C. Ebrecht[13], Diederik J. Opperman[14], Theo Sagmeister[15], Christoph Buhlheller[15,16], Tea Pavkov-Keller[15,17], Manoj K. Rathinaswamy[18], Udit Dalwadi[19], Calvin K. Yip[19], John E. Burke[18], K. Christopher Garcia[9,10,11,20], Nick V. Grishin[6,7,21],

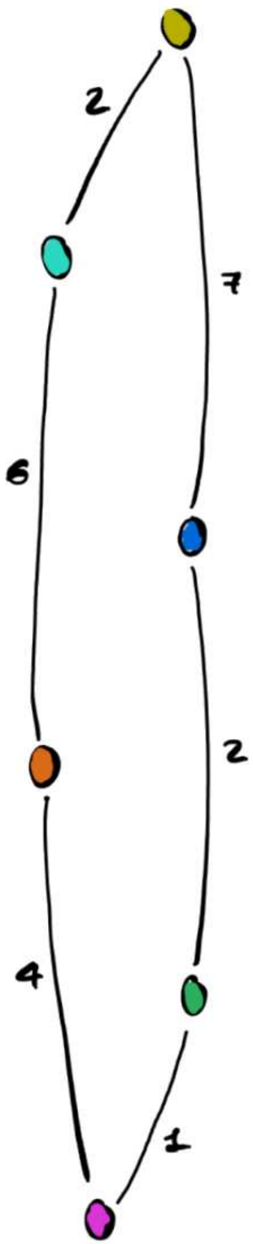
DISTANCE GEOMETRY



GIVEN A CERTAIN NUMBER OF STICKS WITH LABELED VERTICES, CONSTRUCT A GEOMETRICAL FIGURE WHERE EVERY VERTEX IS PLACED IN A UNIQUE POSITION.

THIS PROBLEM IS NP-HARD

A Special Class of Instances in 1D



Subset Sum vs cycleDGP

cycleDGP1 :

given $d_i \in \mathbb{N}_+$

are there $y_i \in \{-1, 1\}$

such that $\sum d_i y_i = 0$?

Define variables $x_i = \frac{y_i + 1}{2}$ $\quad (x_i \in \{0, 1\})$

$\longrightarrow y_i = 2x_i - 1$

$$\sum d_i y_i =$$

$$= \sum d_i (2x_i - 1) =$$

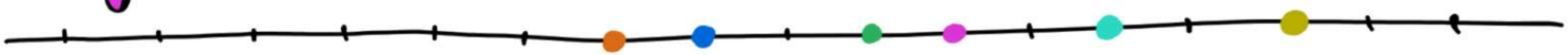
$$= 2 \sum d_i x_i - \sum d_i = 0$$

$$\Longrightarrow \underbrace{\sum (2d_i) x_i}_{\text{still in } \mathbb{N}} = \underbrace{\sum d_i}_{\text{target}}$$

MAIN OPERATIONS:

SUMS AND PRODUCTS

OF REAL NUMBERS

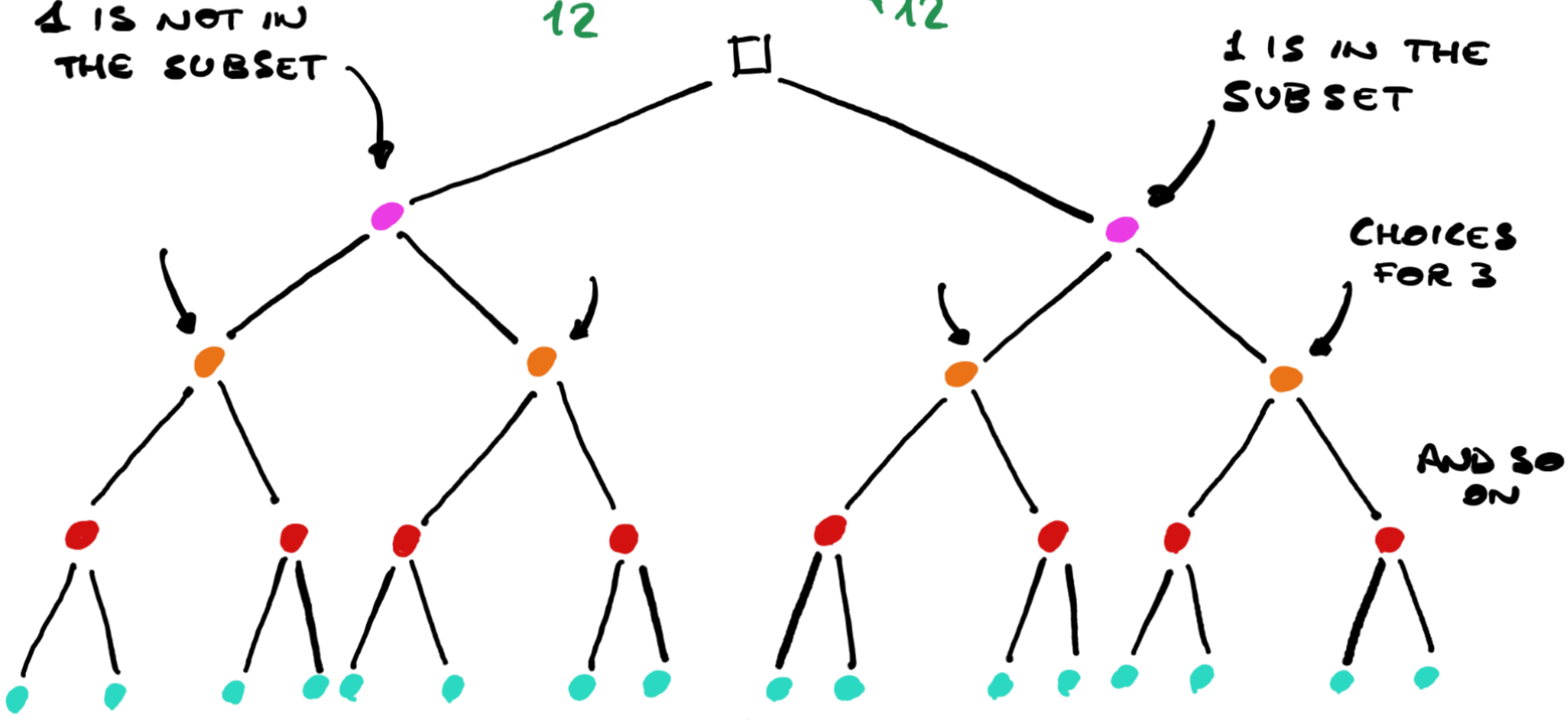


Subset Sum

Is there any subset of S whose elements sum up to t?

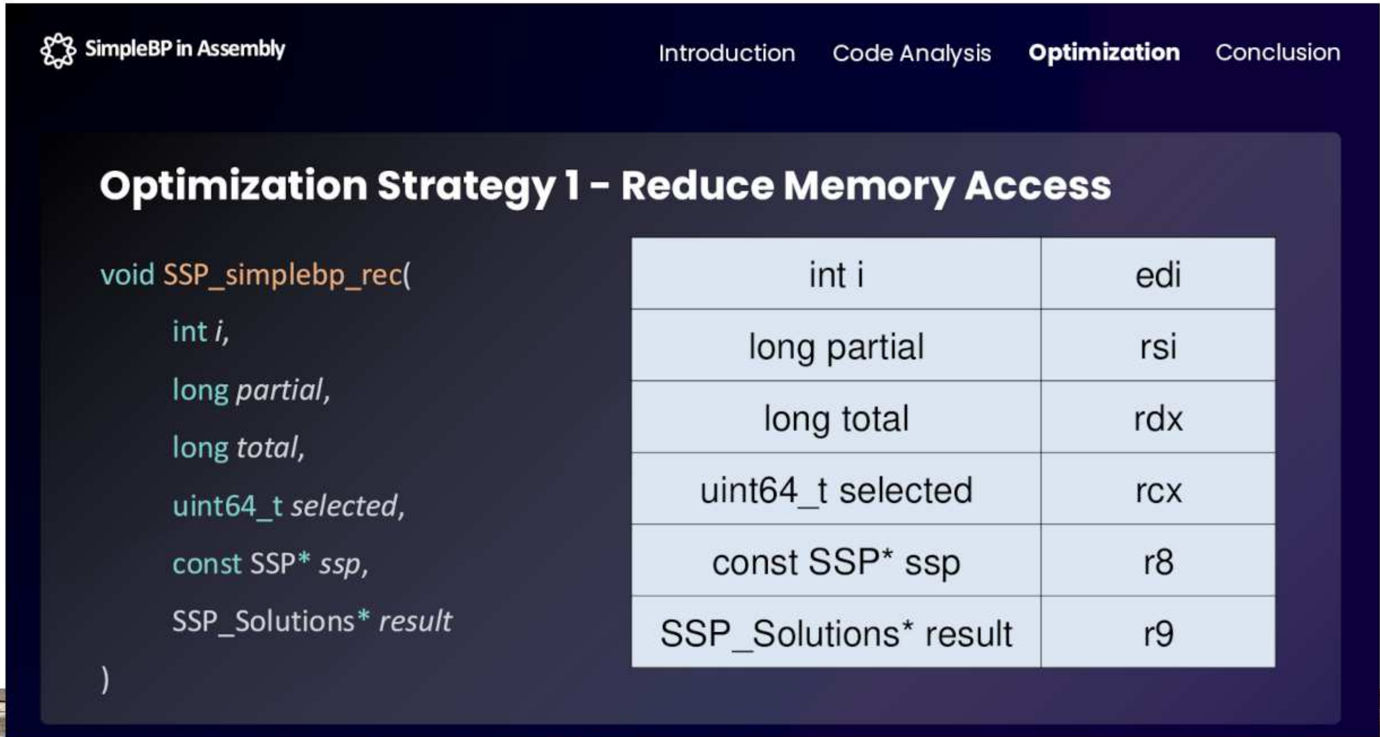
$$S = \{1, 3, 5, 7, 2, 11, 4\}; \quad t = 12$$

12 12



Subset Sum

Even if it has exponential worst-case complexity, it is possible to design ad-hoc efficient implementations



Subset Sum

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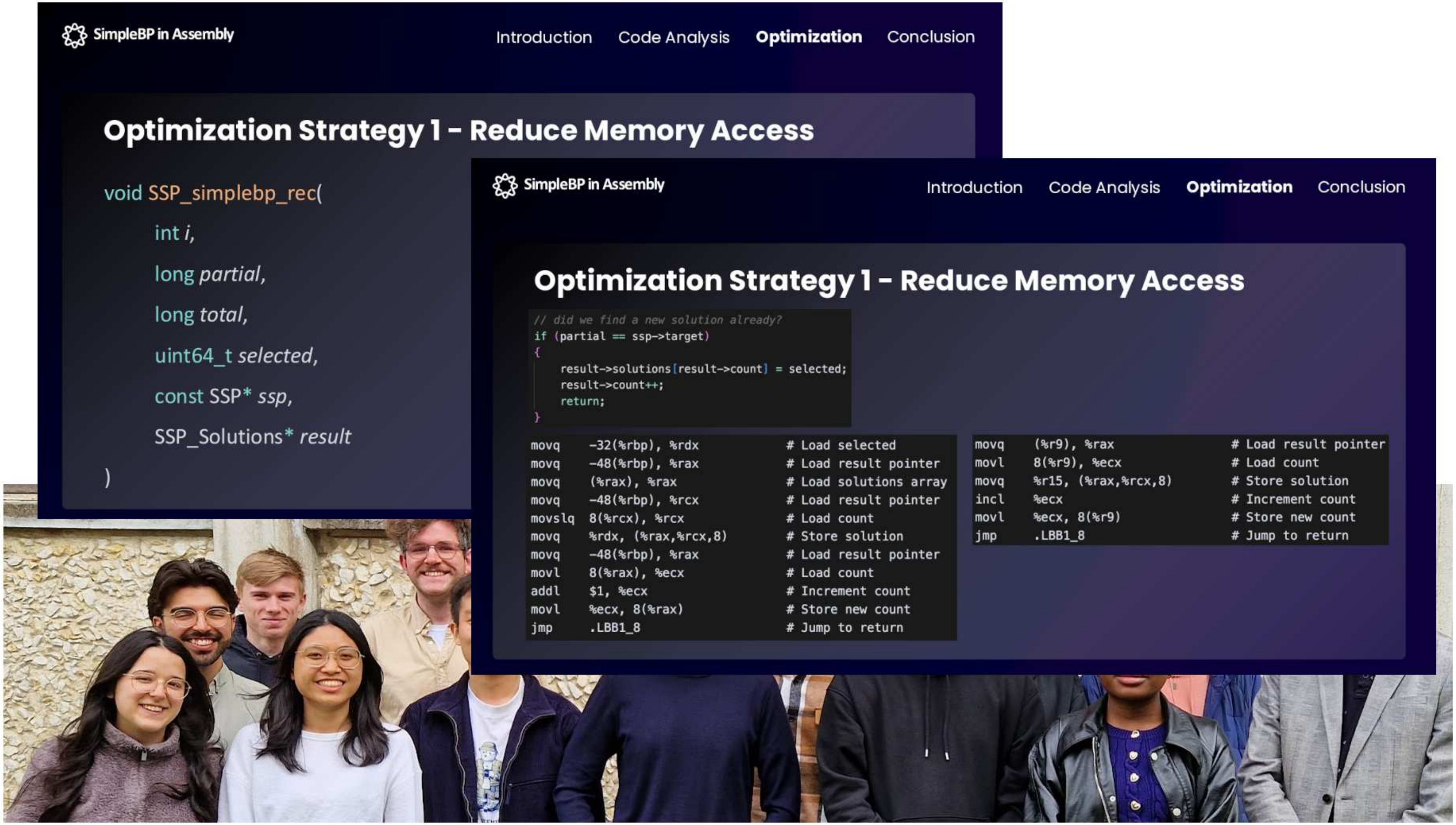

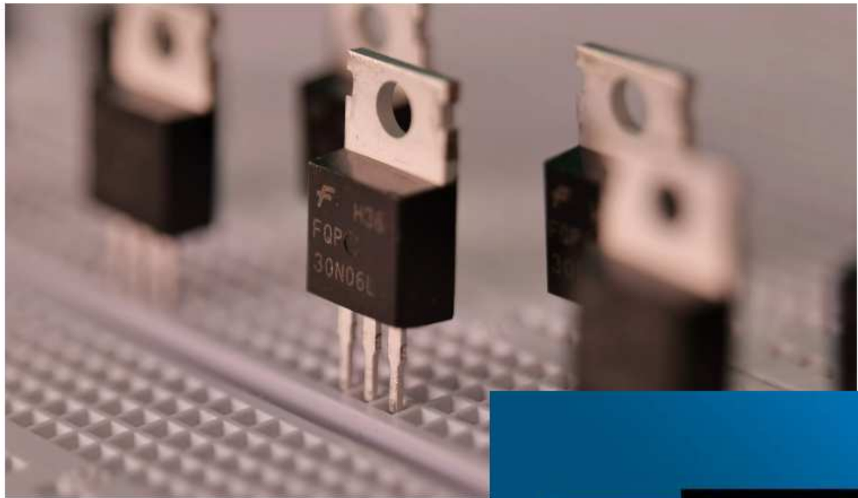


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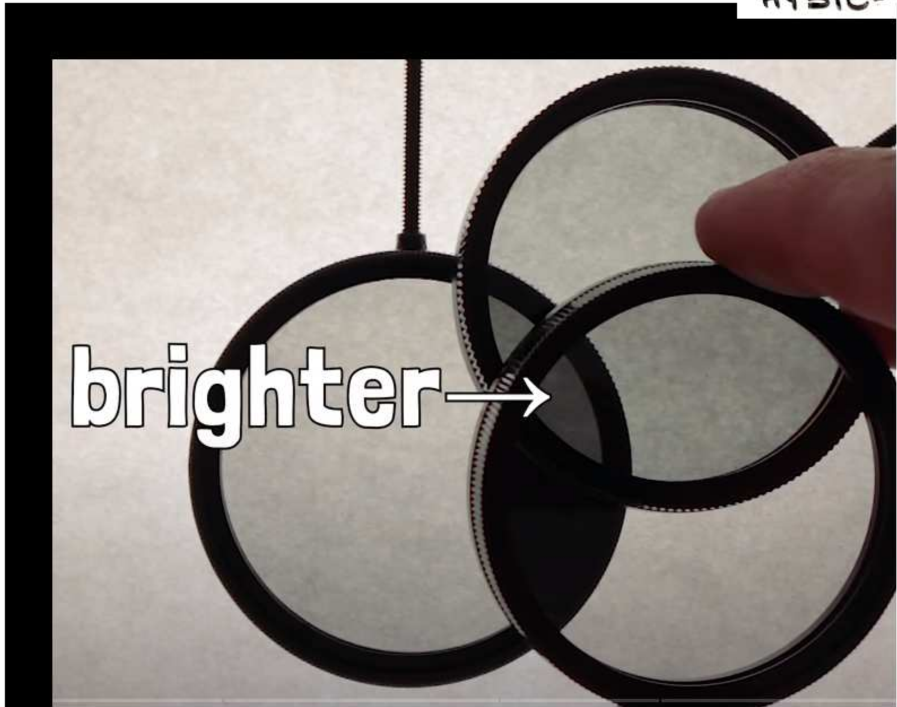
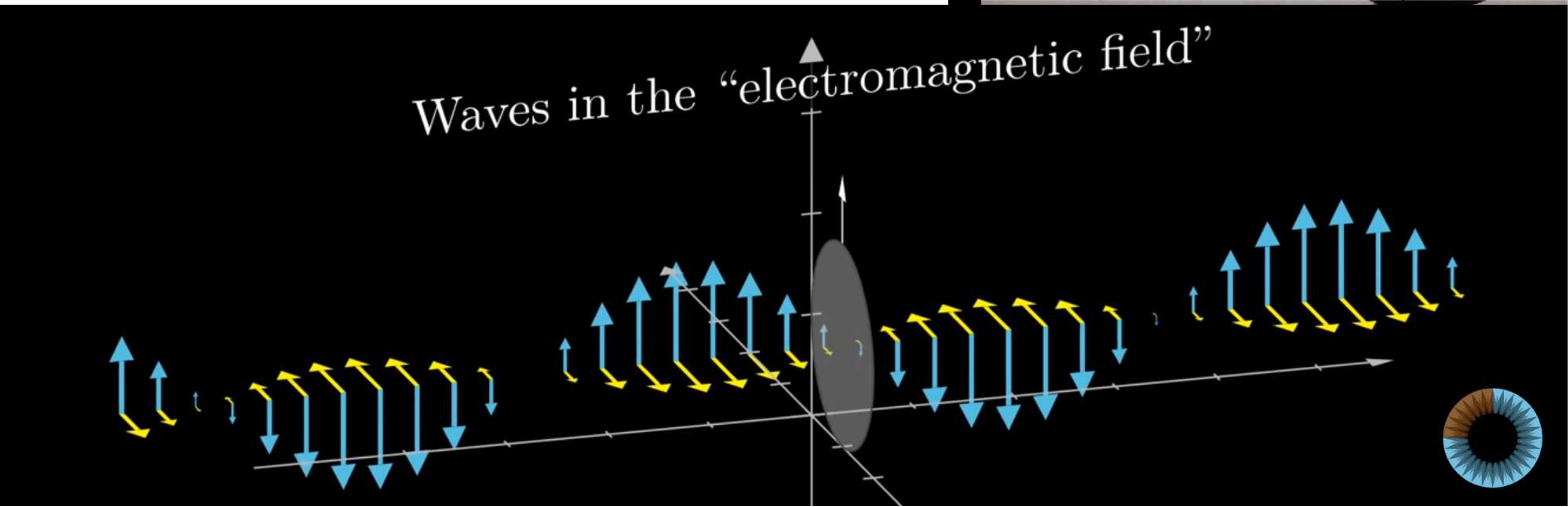
intel CORE i9 Extreme
intel CORE i7 X-series
intel CORE i5 X-series


brighter


Waves in the “electromagnetic field”

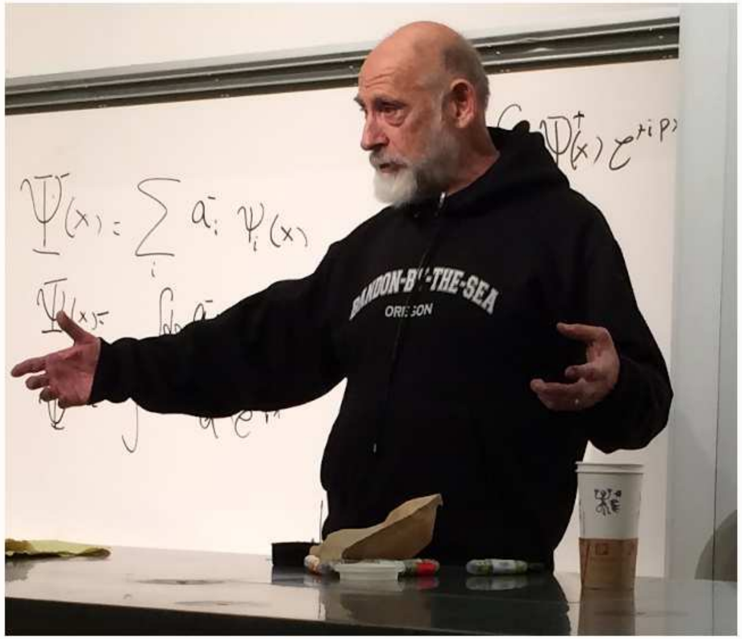
POLARIZATION FOR PHOTONS AND QBITS

LIGHT POLARIZATION IS ONE OF THE POSSIBLE WAYS TO IMPLEMENT QBITS WITH PHOTONS:

$$\alpha|H\rangle + \beta|V\rangle = \begin{pmatrix} \alpha \\ \beta \end{pmatrix} \quad \alpha, \beta \in \mathbb{C}$$

BECAUSE OF THE NORMALIZATION CONSTRAINT $(\alpha^2 + \beta^2 = 1)$ AND THE FACT THAT THE GLOBAL PHASE PLAYS NO ROLE $(e^{i\omega})$ ONE QBIT ONLY ADMITS TWO DEGREES OF FREEDOM.

JONES MATRICES ARE OPERATORS CAPABLE TO EMULATE THE EFFECT OF OPTIC DEVICES ON PHOTONS.

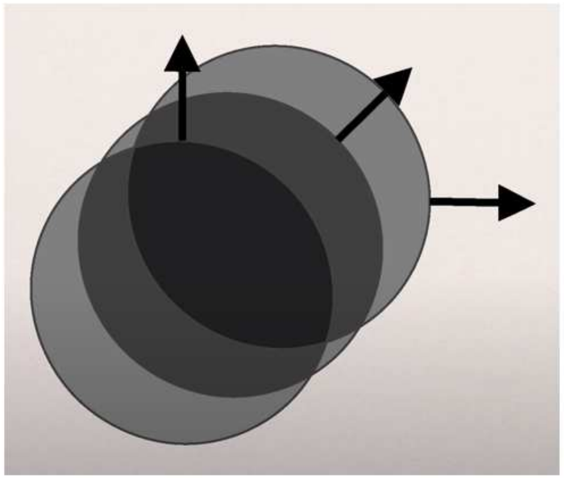


LEONARD SUSSKIND STANFORD UNIVERSITY

JONES MATRICES FOR POLARIZERS

FOCUS ON LINEAR POLARIZERS

HORIZONTAL	VERTICAL	DIAG. +45°	DIAG −45°
$\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$	$\frac{1}{2}\begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$	$\frac{1}{2}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}$
$\|H\rangle$	$\|V\rangle$	$\|D\rangle$	$\|A\rangle$

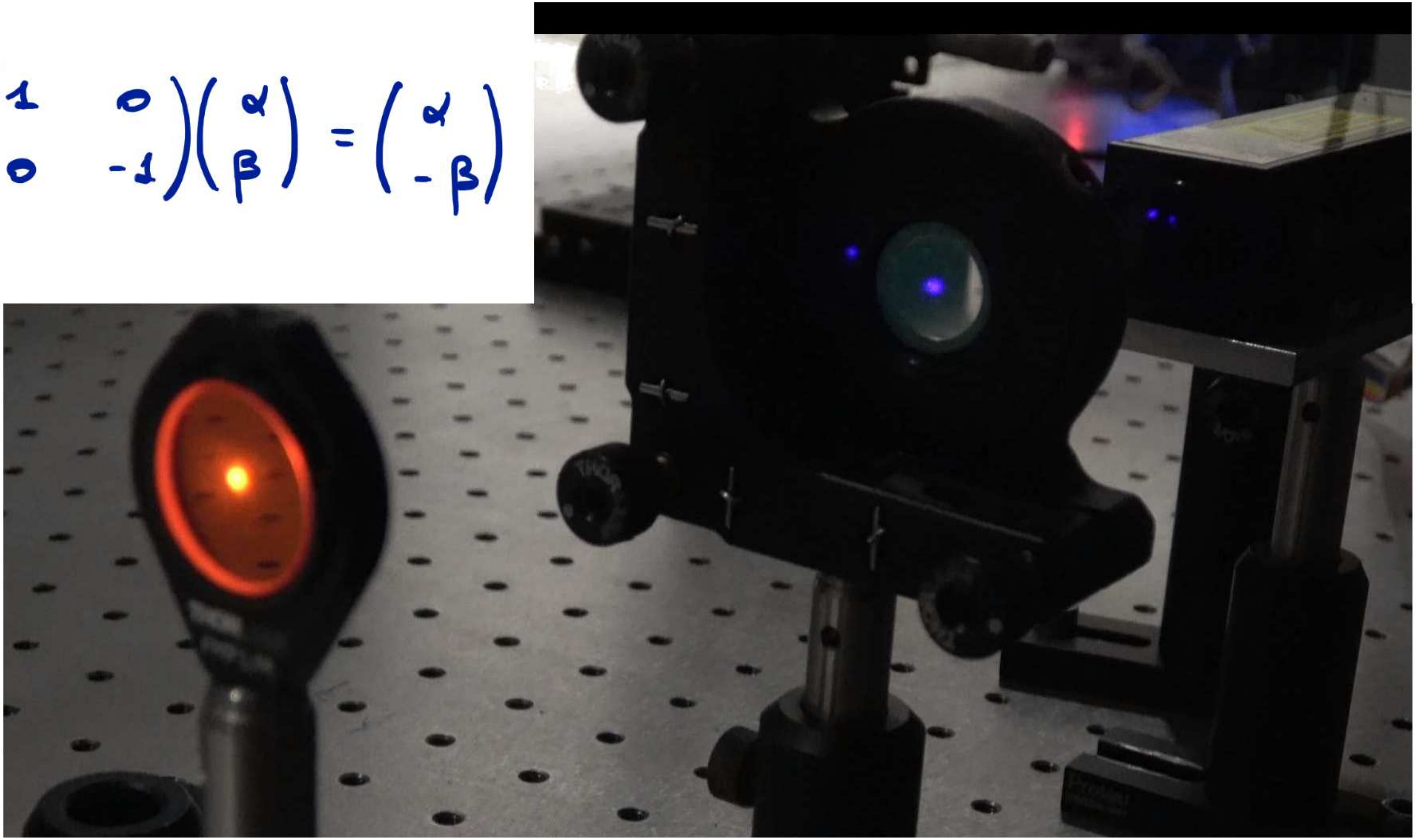


DEPENDING ON THE CURRENT STATE $\begin{pmatrix} \alpha \\ \beta \end{pmatrix}$, PART OF THE LIGHT PASSES THROUGH, ANOTHER PART IS INSTEAD ABSORBED.

THE HALF WAVE PLATE

IT ALLOWS US TO "TILT" THE POLARIZATION:

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \alpha \\ -\beta \end{pmatrix}$$



DIFFERENTLY FROM POLARIZERS, NO LIGHT IS ABSORBED (IN IDEAL CONDITIONS)

ENCODING DATA WITH SPATIAL LIGHT MODULATORS

- IT IMPRINTS A GIVEN PHASE TO THE LIGHT BEAM REACHING EVERY PIXEL
- 2^m DIFFERENT DATA VALUES δ CAN BE ASSOCIATED TO THE PHASE (eg. $m=8 \Rightarrow 256$ values)
- BUT HOW TO READ/EXPLOIT THESE DATA ONCE ENCODED?

$$\Downarrow$$

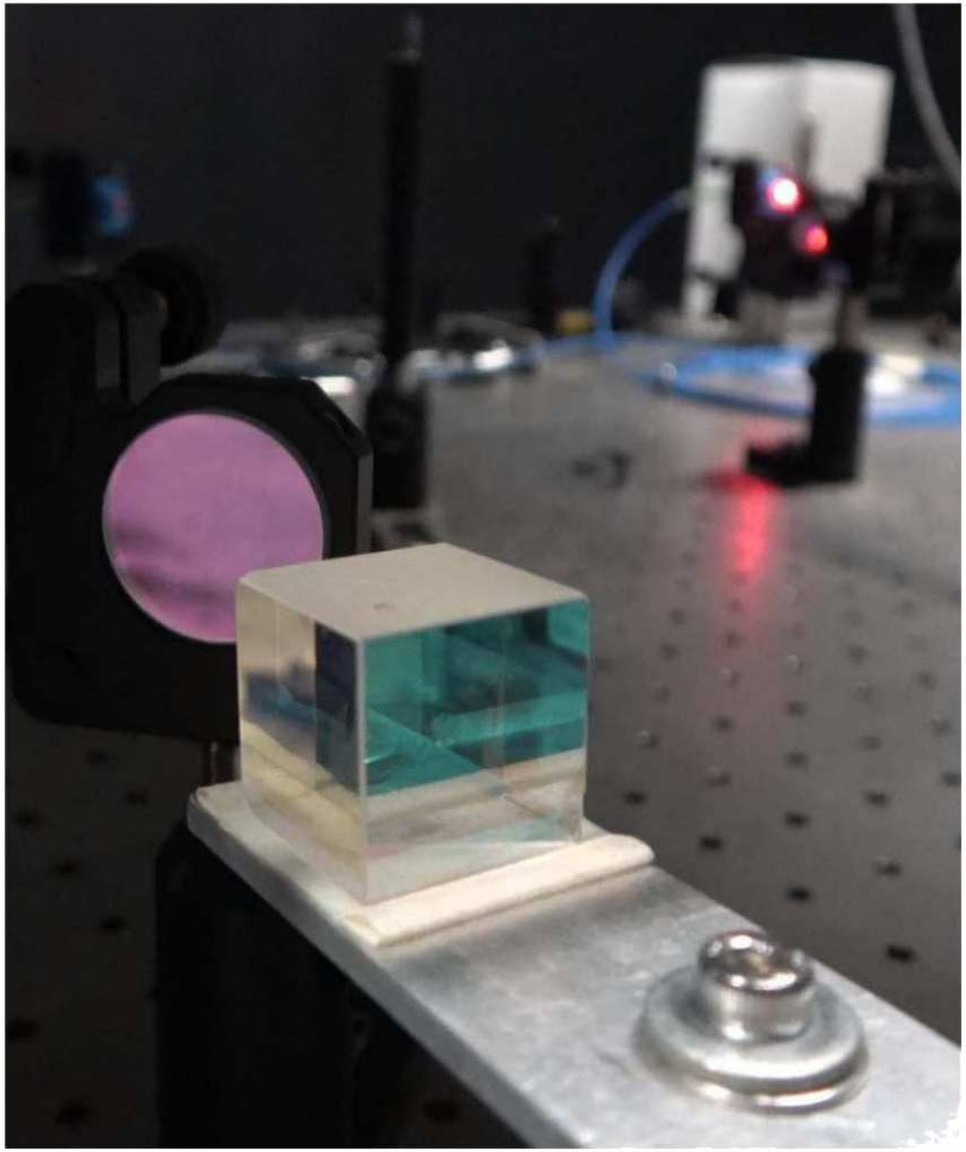
USE THE FACT THAT SLMS ALTER THE PHASE ONLY ALONG ONE OF THE 2 POLARIZATION COMPONENTS (eg. Horizontal)

$$\begin{pmatrix} e^{i\delta} & 0 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \alpha e^{i\delta} & 0 \\ 0 & \beta \end{pmatrix}$$

From Polarization Modulation to Intensity Profile

- Use a Half-Wave Plate
  ($\theta = -45°$, $(D,A) \rightarrow (H,V)$)

- Use a Polarization Beam Splitter
  (we select the H component only)



This is equivalent to performing a polarization projection on H

Reference: Paul, Hor-Meyll, Ribeiro, Walborn, Scientific Reports 4, 5337, 2014

MULTIPLYING TWO REAL NUMBERS

$(a = 1-\cos\delta_a ,\ b = 1-\cos\delta_b)$

MONOCHROMATIC
D-POLARIZED LIGHT
FROM LASER

$$\frac{1}{\sqrt{2}}\begin{pmatrix}1\\1\end{pmatrix} \xrightarrow[\text{SLM}]{} \frac{1}{\sqrt{2}}\begin{pmatrix}e^{i\delta_a} & 0\\ 1 & 0\end{pmatrix}\begin{pmatrix}1\\1\end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix}e^{i\delta_a}\\ 1\end{pmatrix}$$

HWP flip
D → H, A → V

$$\frac{1}{2}\begin{pmatrix}e^{i\delta_a}-1\\ -e^{i\delta_a}-1\end{pmatrix} \longleftarrow \frac{1}{\sqrt{2}}\begin{pmatrix}1/\sqrt{2} & -1/\sqrt{2}\\ -1/\sqrt{2} & -1/\sqrt{2}\end{pmatrix}\begin{pmatrix}e^{i\delta_a}\\ 1\end{pmatrix}$$

PBS
H ONLY

$$\frac{1}{2}\begin{pmatrix}e^{i\delta_a}-1\\ 0\end{pmatrix} \xrightarrow{\text{SOME MATH}} (1-\cos\delta_a)\begin{pmatrix}1\\0\end{pmatrix}$$

WE WRITE $e^{i\delta_a}-1$ IN THE FORM $\alpha e^{i\beta}$
WE CAN THEN NEGLECT THE GLOBAL PHASE

Multiplying two Real Numbers

$(a = 1-\cos\delta_a,\ b = 1-\cos\delta_b)$

Monochromatic
D-polarized light
from laser

$$\frac{1}{\sqrt{2}}\begin{pmatrix}1\\1\end{pmatrix} \xrightarrow[\text{STEP 1}]{} (1-\cos\delta_a)\begin{pmatrix}1\\0\end{pmatrix} \xrightarrow[\text{D-pol.}]{} \frac{1}{2}(1-\cos\delta_a)\begin{pmatrix}1 & 1\\1 & 1\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix}$$

$$\longrightarrow \frac{1}{2}\begin{pmatrix}1-\cos\delta_a\\1-\cos\delta_a\end{pmatrix}$$

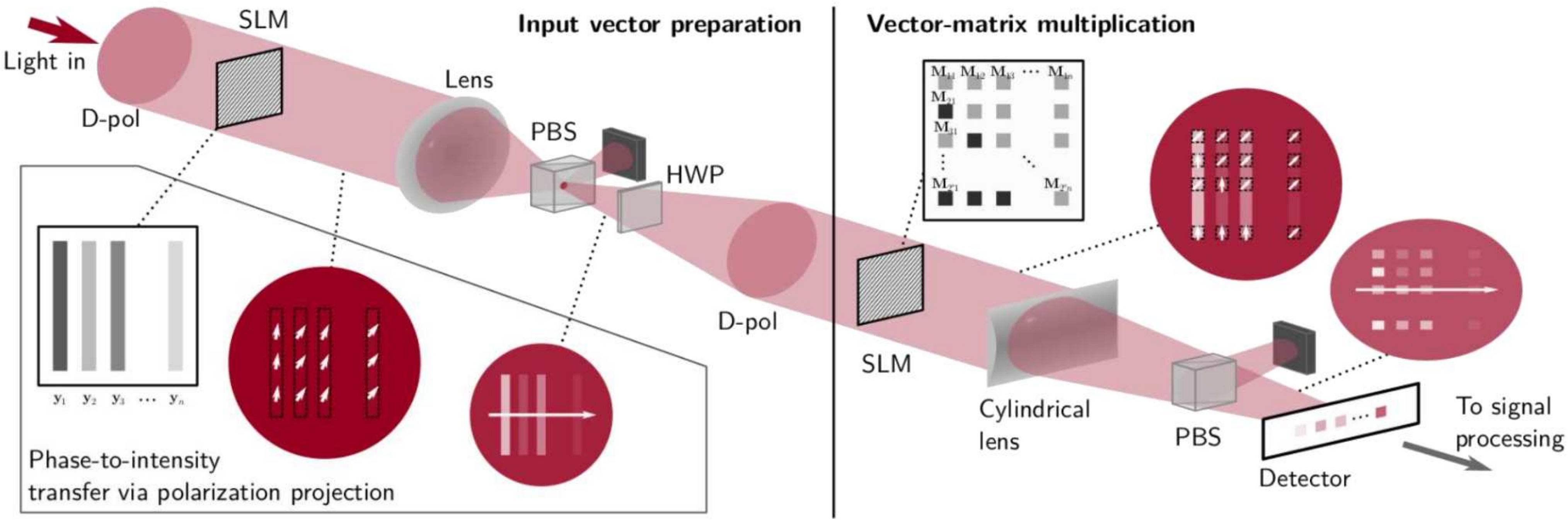
$$c\begin{pmatrix}1\\0\end{pmatrix} \longleftarrow \frac{(1-\cos\delta_a)(1-\cos\delta_b)}{\sqrt{2}}\begin{pmatrix}1\\0\end{pmatrix} \xleftarrow[\text{STEP 2}]{} \frac{1}{2}\begin{pmatrix}1-\cos\delta_a\\1-\cos\delta_a\end{pmatrix}$$

OUR INTENSITY MEASURE

IDENTICAL BUT WITH DIFFERENT INPUT (δ_b)

$$\boxed{ab = \sqrt{2}\,c}$$

Our Full-Optical Processor



Ongoing Research:

- Theory: Other degrees of Freedom?
- Practise: Hardware Implementation

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Associate Professor

IRISA, University of Rennes

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Hey guys, I've just tried this new Google's NotebookLM functionality, where you provide a bunch of sources and it generates for you an audio summary of its content in the form a podcast.
This is what it was produced from one of our papers: a podcast about our optical processor! Just amazing.

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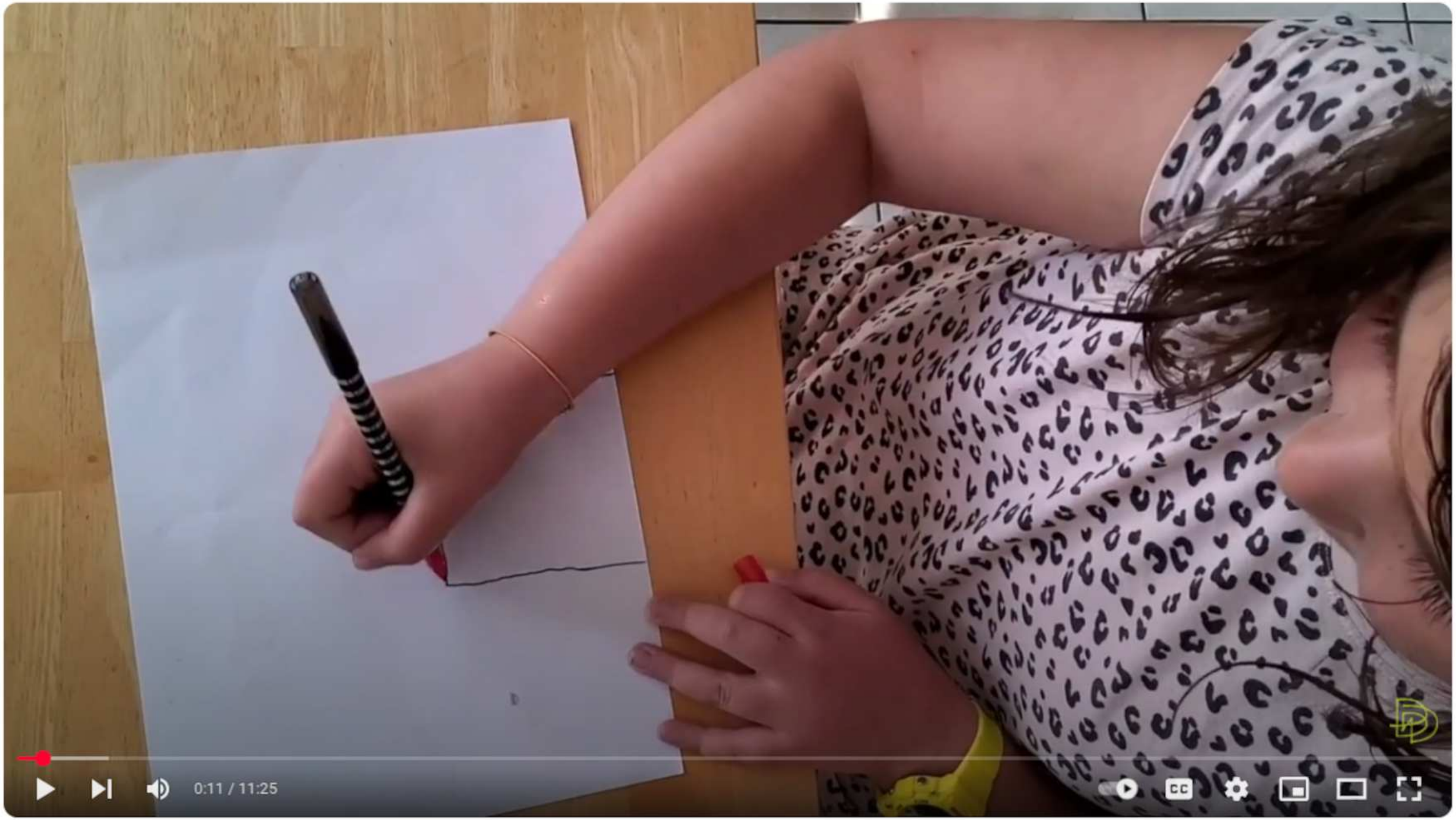

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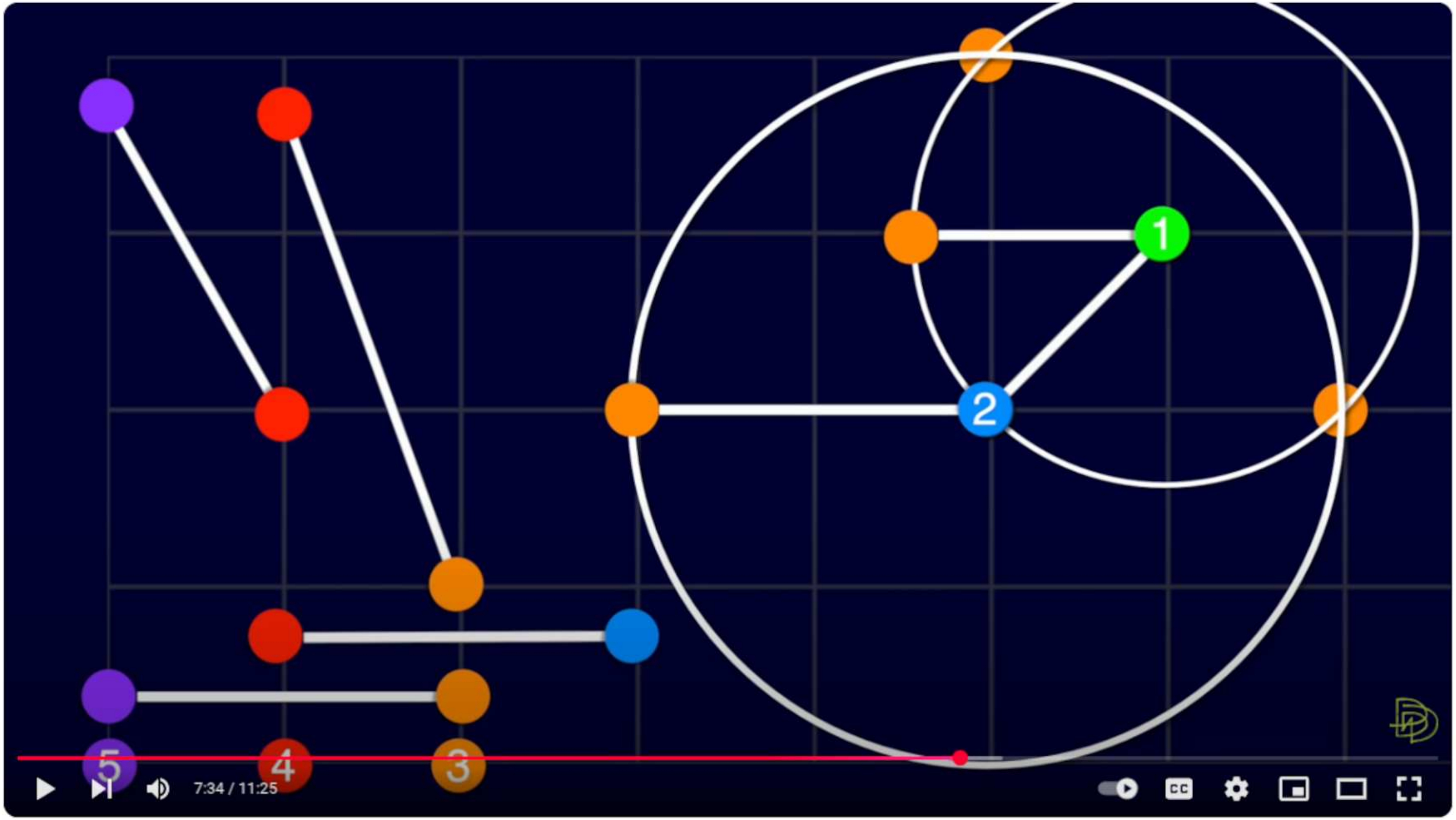

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Thanks !

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