

čo nám príroda (ne)dovolí vypočítat'



Daniel Nagaj

| S A S

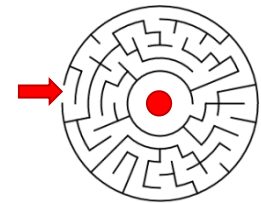


konferencia preveda
6/9/2016

1

hlavolamy

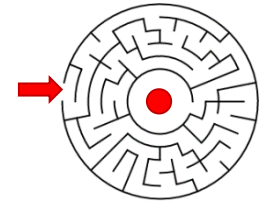
niektoré ľahké, iné ťažké



1

hlavolamy

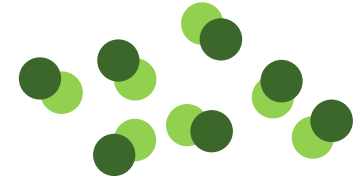
niektoré ľahké, iné ťažké



2

kvantové ihrisko

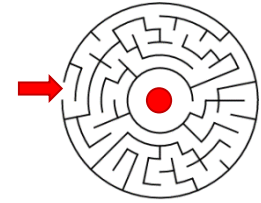
je obrovské a hrať treba v superpozícii



1

hlavolamy

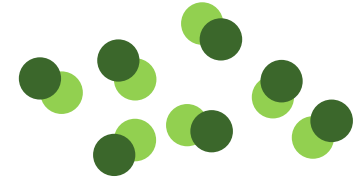
niektoré ľahké, iné ťažké



2

kvantové ihrisko

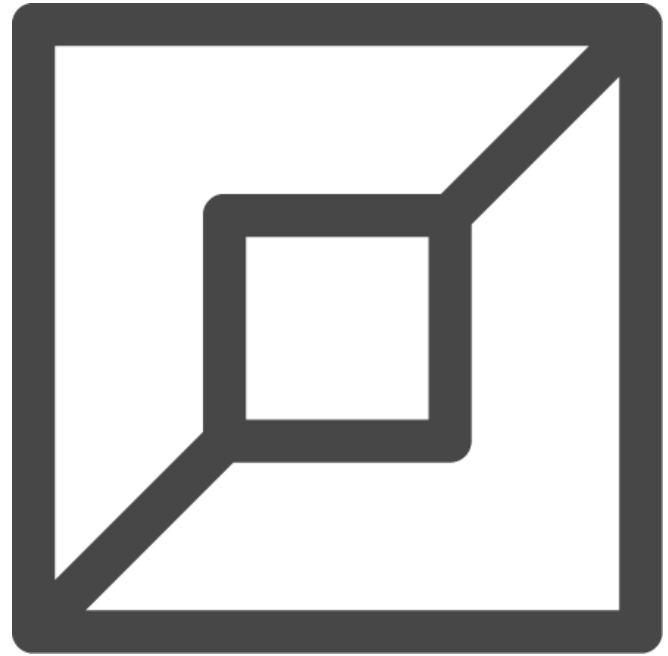
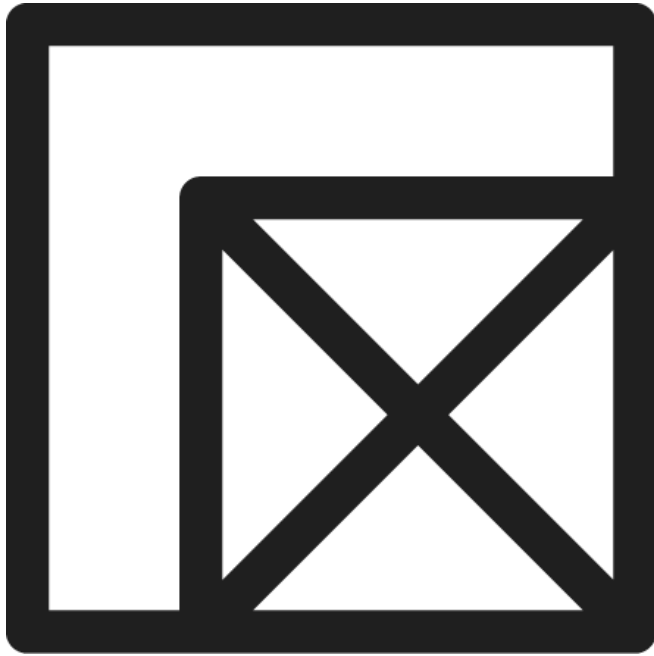
je obrovské a hrať treba v superpozícii



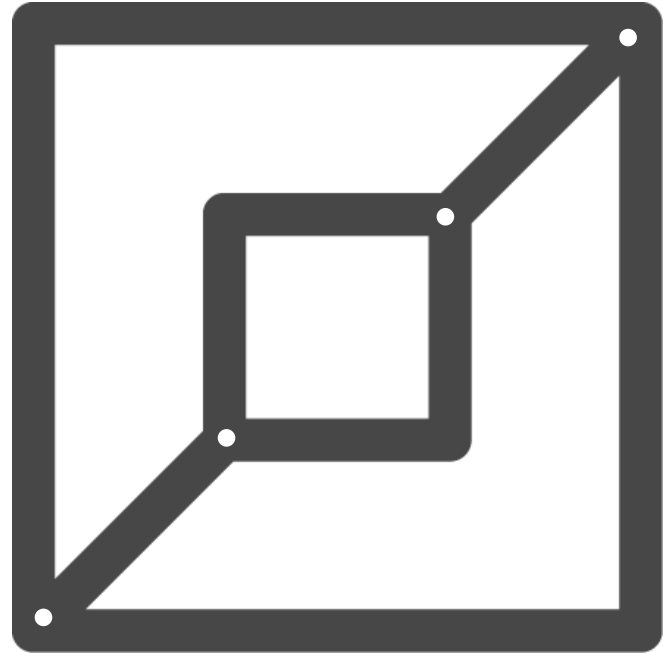
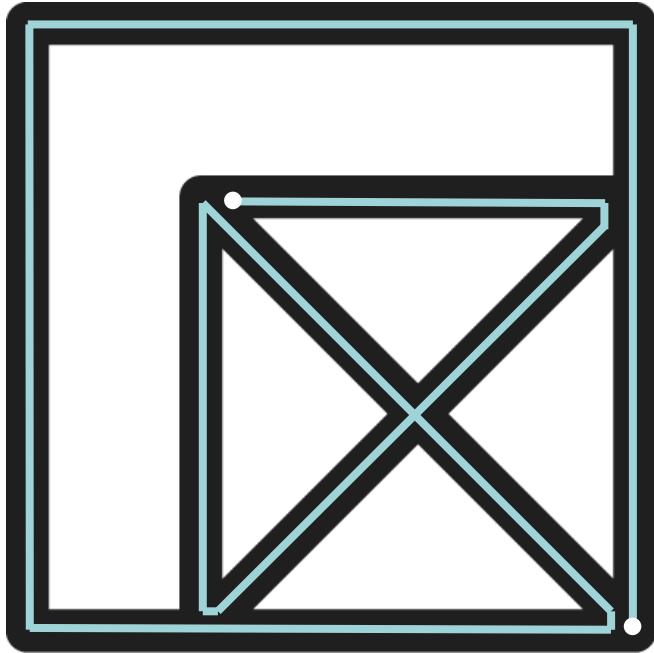
3

čo (ne)dokážeme

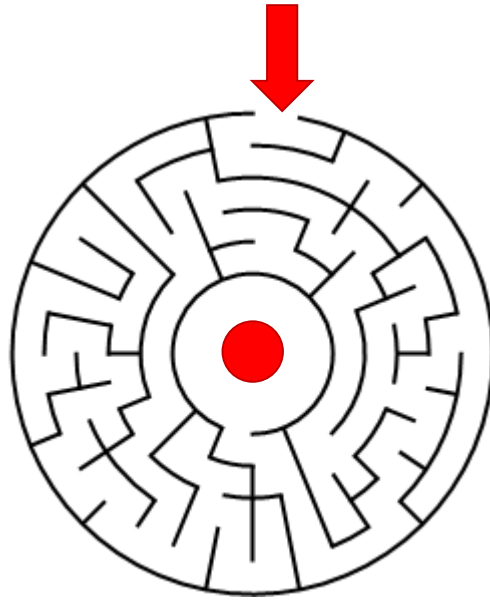
(ani) na počítačoch, ktoré ešte nemáme



Bridges of Koenigsberg

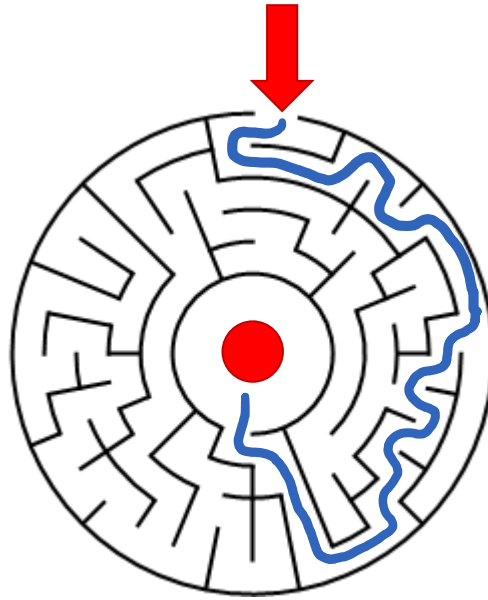


Bridges of Koenigsberg



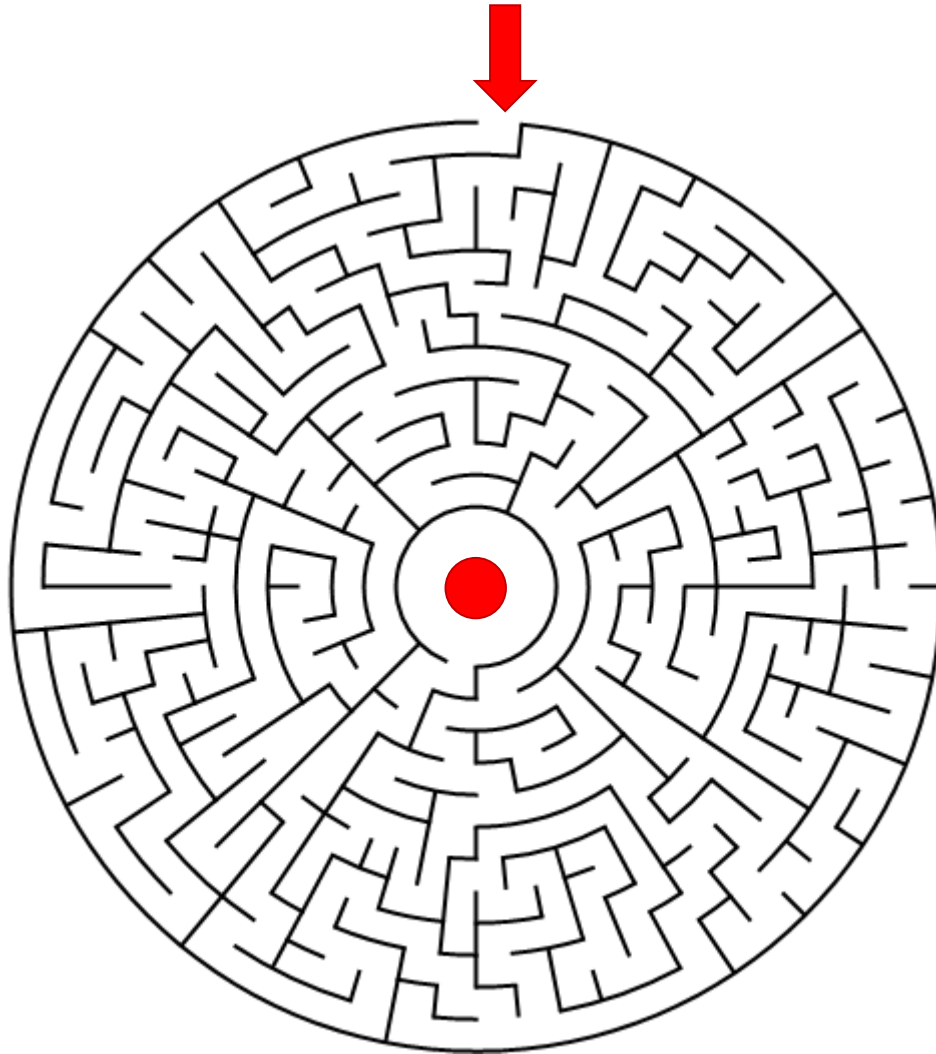
Shortest path

[www.mazegenerator.net]



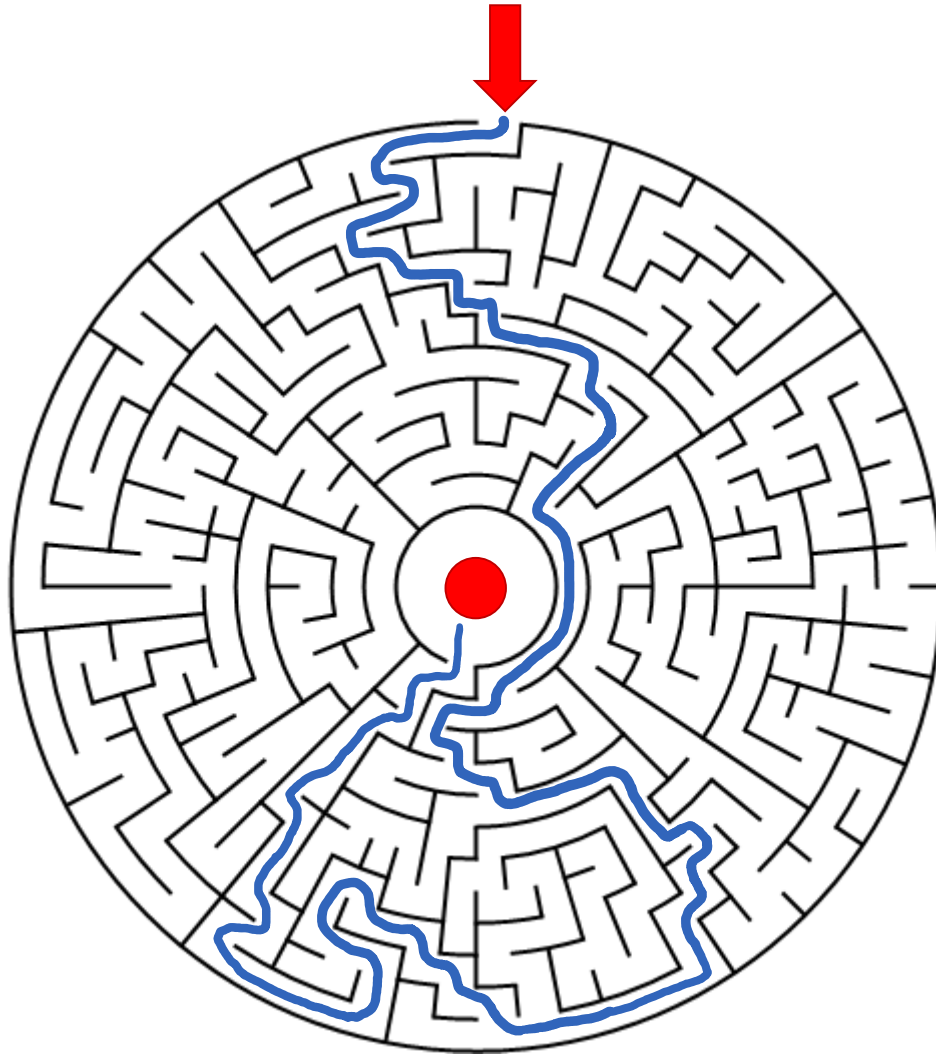
Shortest path

[www.mazegenerator.net]



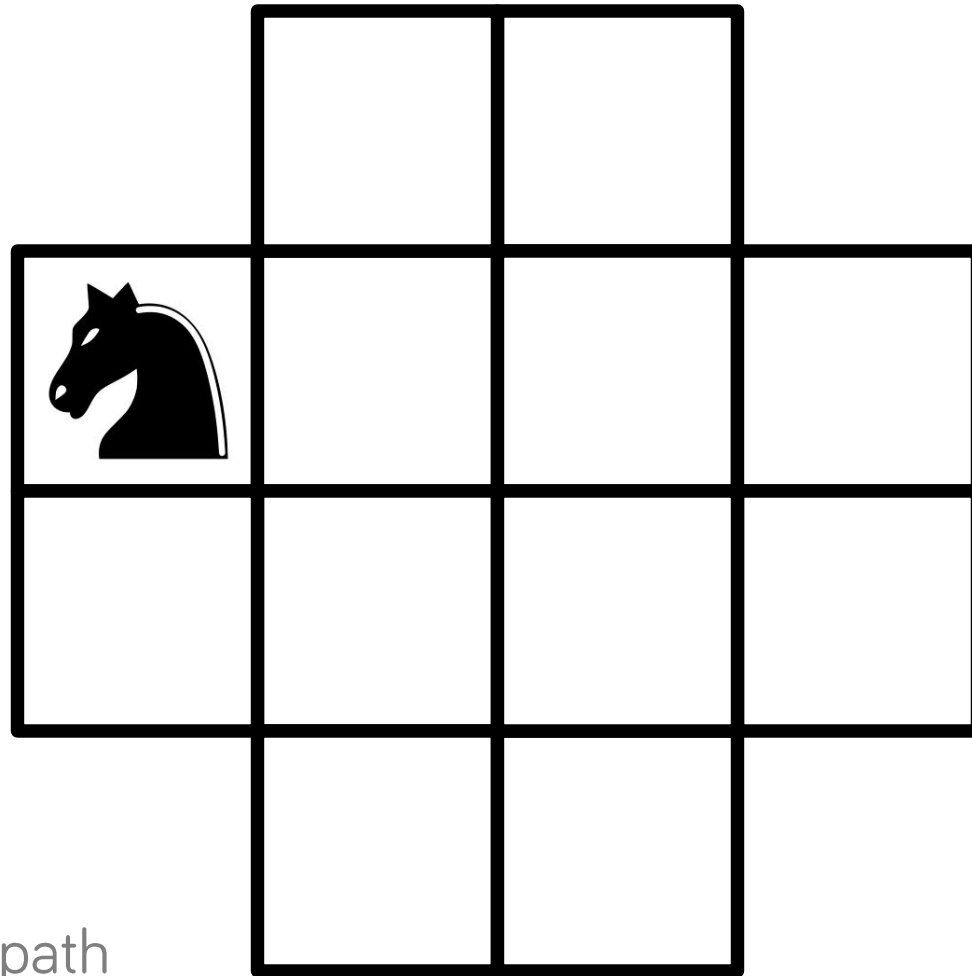
Shortest path

[www.mazegenerator.net]

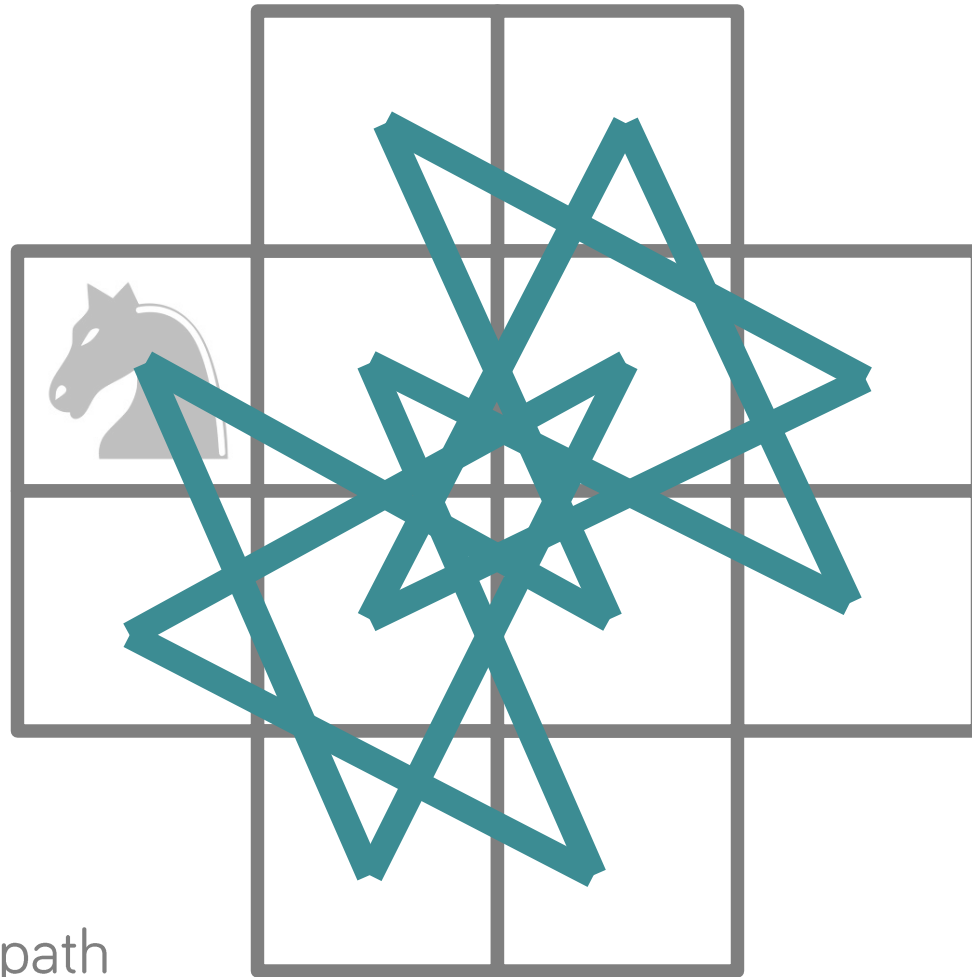


Shortest path

[www.mazegenerator.net]



Hamiltonian path

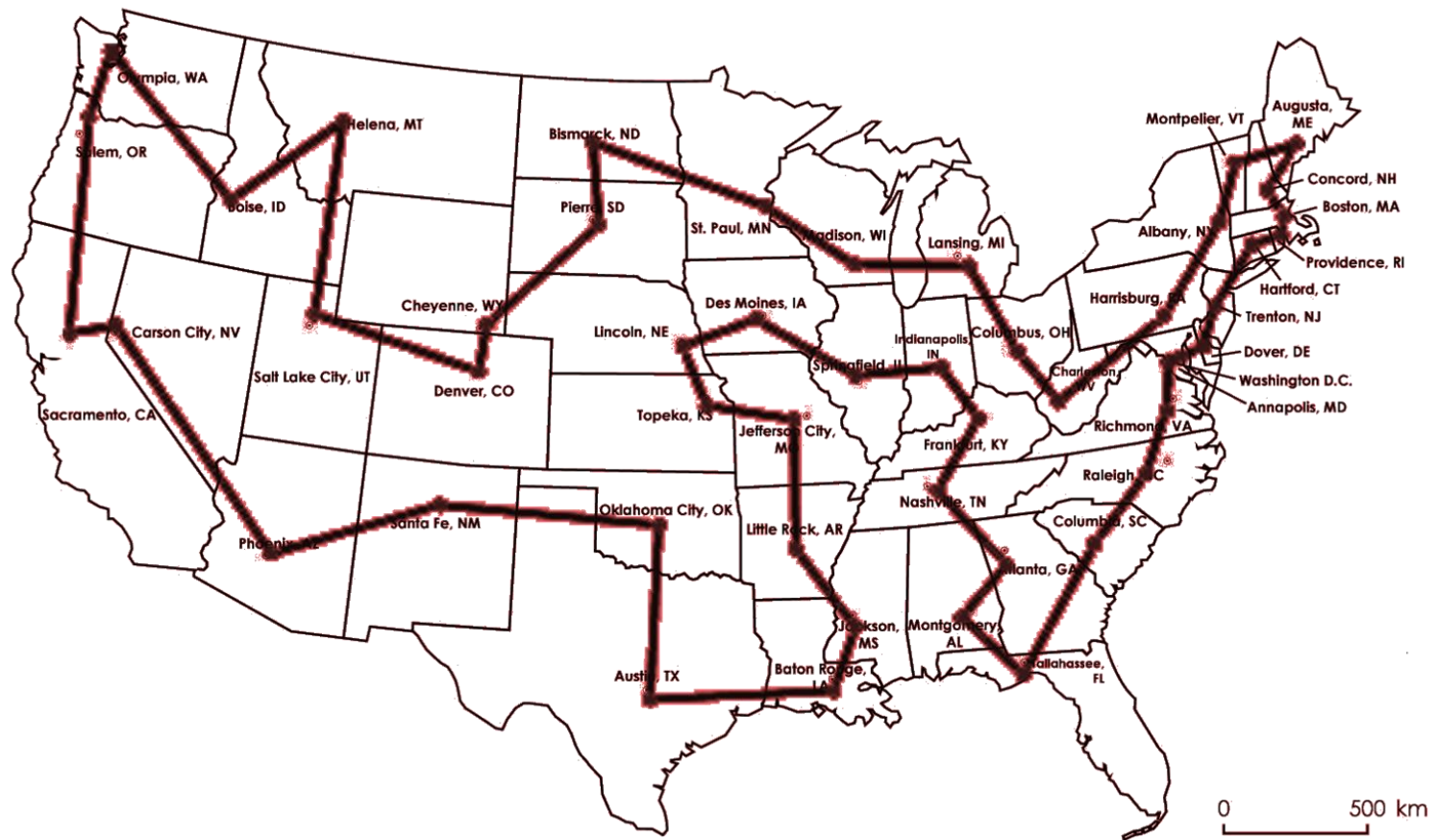


Hamiltonian path



Traveling salesman

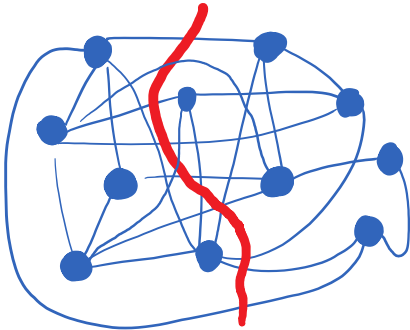
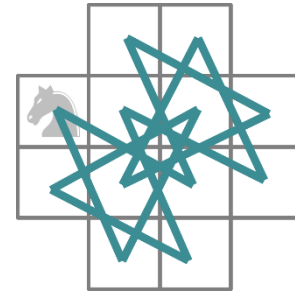
[www.superteacherworksheets.com, sas.com]



Traveling salesman

[www.superteacherworksheets.com, sas.com]

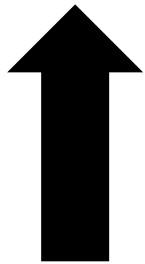
NP-ÚPLNOST



$$\begin{aligned} &+ 182 + 223 - 314 + 651 \\ &- 410 + 245 - 677 - 62 \\ &+ 3 + 916 - 120 + 874 \\ &+ 399 - 725 - 58 - 403, \\ &= 1500 \end{aligned}$$

ZLOŽITOSŤ

P



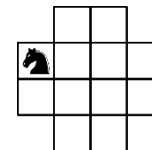
vyriešiť



ZLOŽITOSŤ

NP

overiť



P

vyriešiť



ZLOŽITOSŤ

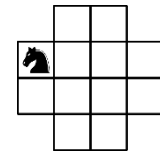
#P

riešení

koľkými
spôsobmi
sa dá ...

NP

overit'



P

vyriešiť



KLASICKY

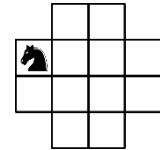
#P

riešení

koľkými
spôsobmi
sa dá ...

NP

overit'



P

vyriešiť



KVANTOVO



???

o dost' viac
vyriešit'

KVANTOVO



???

má to
svoje
limity

o dost' viac
vyriešit'

0

KLASICKÝ

1

SVET

bit

0

KLASICKÝ

1

SVET

bit 11111100000

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KLASICKÝ

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SVET

bit 111111000000

= 2016 = 2048 - 32

0

KVANTOVÝ

1

SVET

01

SUPERPOZÍCIÍ

qubit

1

0

0

KVANTOVÝ

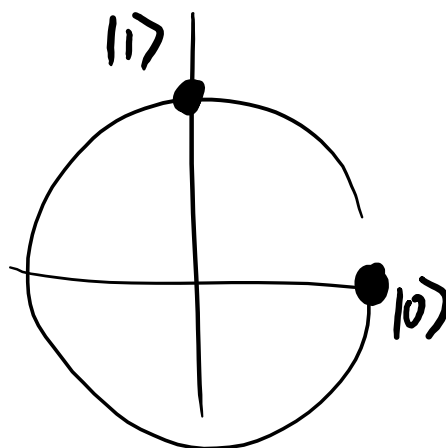
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SVET

1

SUPERPOZÍCIÍ

qubit



1

0

0

KVANTOVÝ

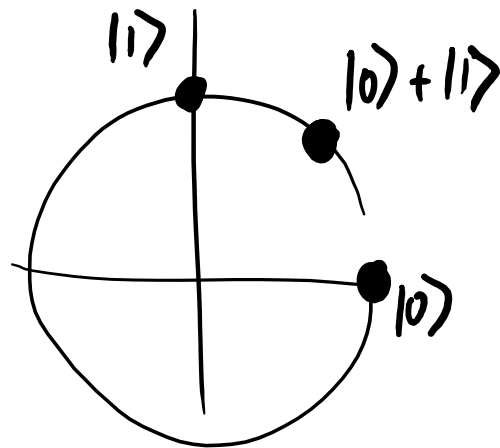
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SVET

1

SUPERPOZÍCIÍ

qubit



1

0

0

KVANTOVÝ

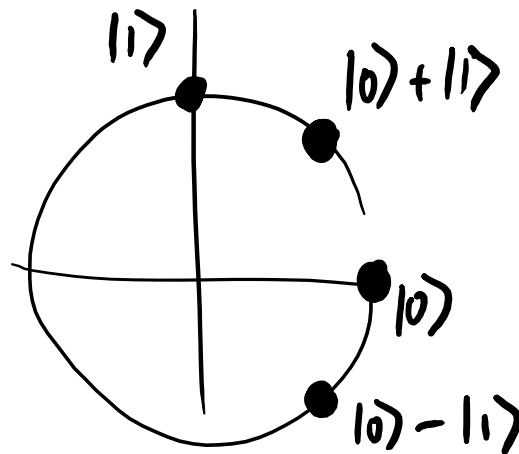
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SVET

1

SUPERPOZÍCIÍ

qubit



1

0

0

KVANTOVÝ

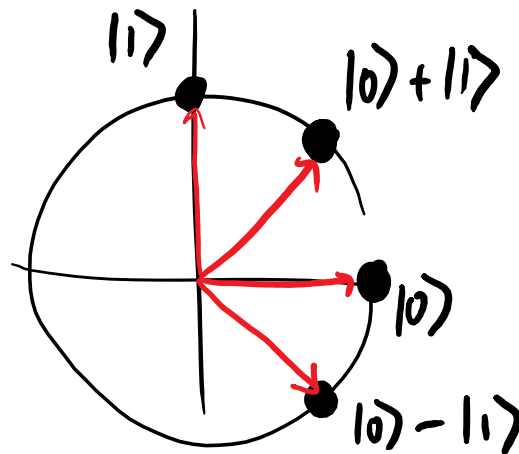
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SVET

1

SUPERPOZÍCIÍ

qubit



1

0

0

KVANTOVÝ

1

SVET

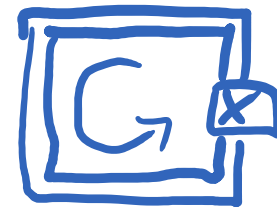
1

SUPERPOZÍCIÍ

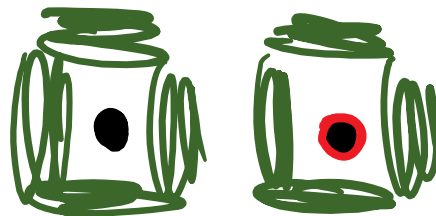
qubit



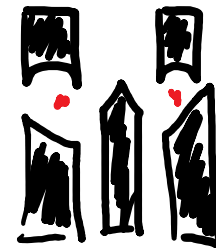
fotón



suprav.
obvod



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v pasci



kvant.
bodka

0

KVANTOVÝ

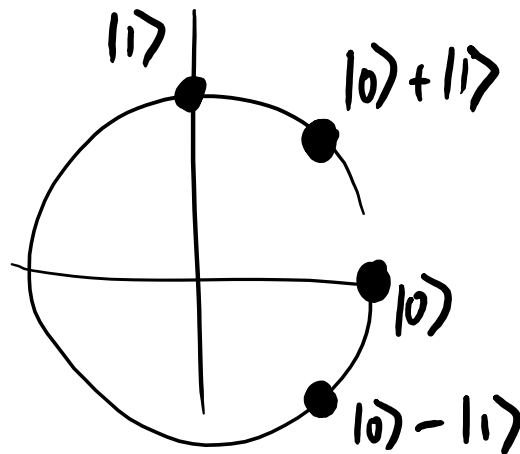
1

SVET

01

SUPERPOZÍCIÍ

1 qubit



0

KVANTOVÝ

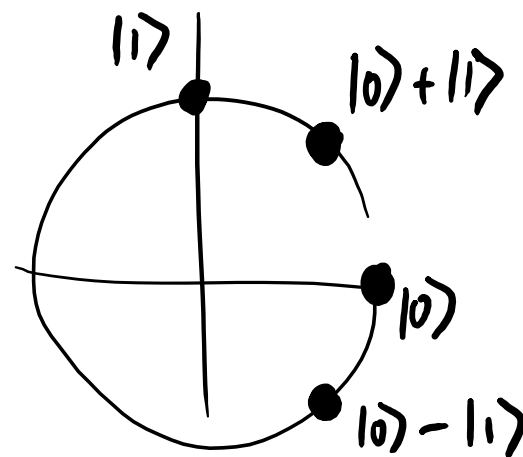
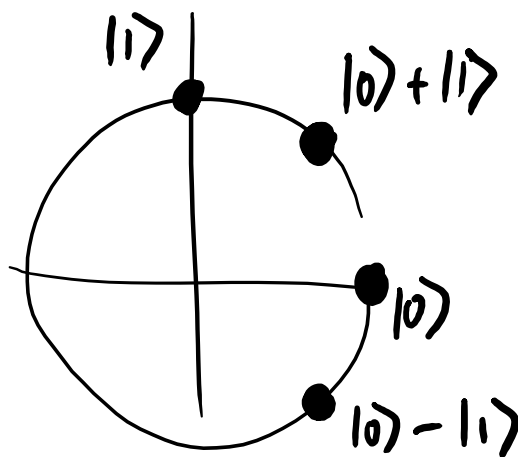
1

SVET

1

SUPERPOZÍCIÍ

2 qubity



0

KVANTOVÝ

1

SVET

01

SUPERPOZÍCIÍ

2 qubity

$$|\psi\rangle = \begin{bmatrix} \dots \\ \dots \\ \dots \\ \dots \end{bmatrix} \begin{matrix} |00\rangle \\ |01\rangle \\ |10\rangle \\ |11\rangle \end{matrix}$$

0

KVANTOVÝ

1

SVET

01

SUPERPOZÍCIÍ

3 qubity

$$|4\rangle = \begin{bmatrix} \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \end{bmatrix} \begin{matrix} |000\rangle \\ |001\rangle \\ |010\rangle \\ |011\rangle \\ |100\rangle \\ |101\rangle \\ |110\rangle \\ |111\rangle \end{matrix}$$

0

KVANTOVÝ

1

SVET

1

SUPERPOZÍCIÍ

N qubitov

$$| \psi \rangle = \begin{bmatrix} \vdots \\ \vdots \end{bmatrix} \quad \updownarrow \quad 2^N$$

N bitov

Kol'ko to zaberie pamäte?

N qubitov

$$| \psi \rangle = \begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix} \quad \updownarrow \quad 2^N$$

N bitov

$$S = 0101101011$$

$\longleftrightarrow$
 N

2^N možných
všetkov

Kol'ko to zaberie pamäte?

N qubitov

$$| \psi \rangle = \begin{bmatrix} \vdots \\ \vdots \end{bmatrix} \quad \begin{matrix} \updownarrow \\ 2^N \end{matrix}$$

AKO

SIMULOVAŤ

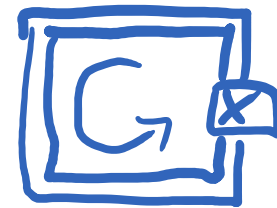
SUPERPOZÍCIE

qubit

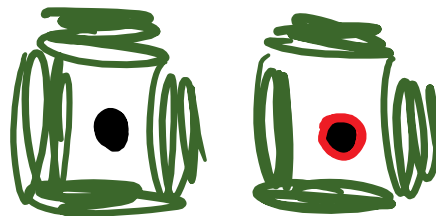
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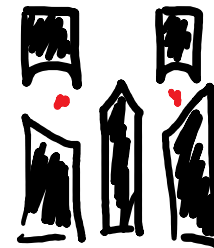
fotón



suprav.
obvod



ión
v pasci



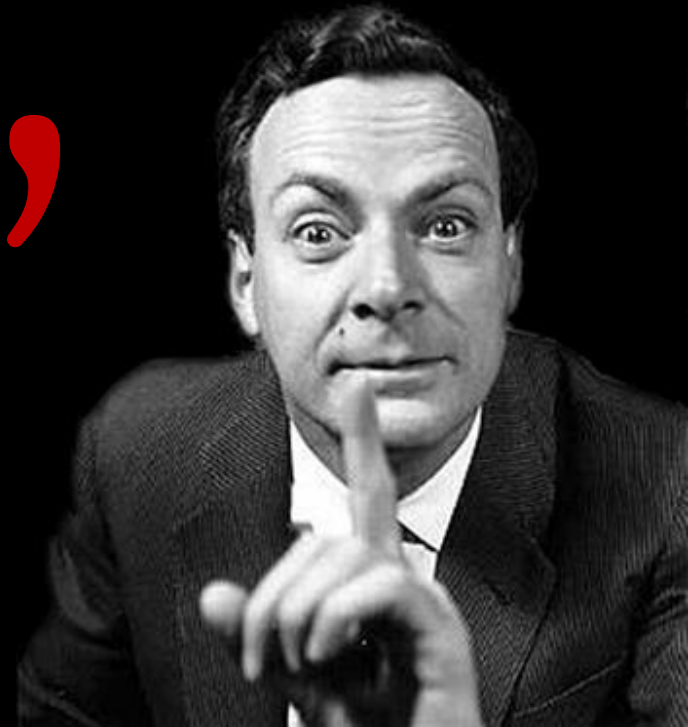
kvant.
bodka

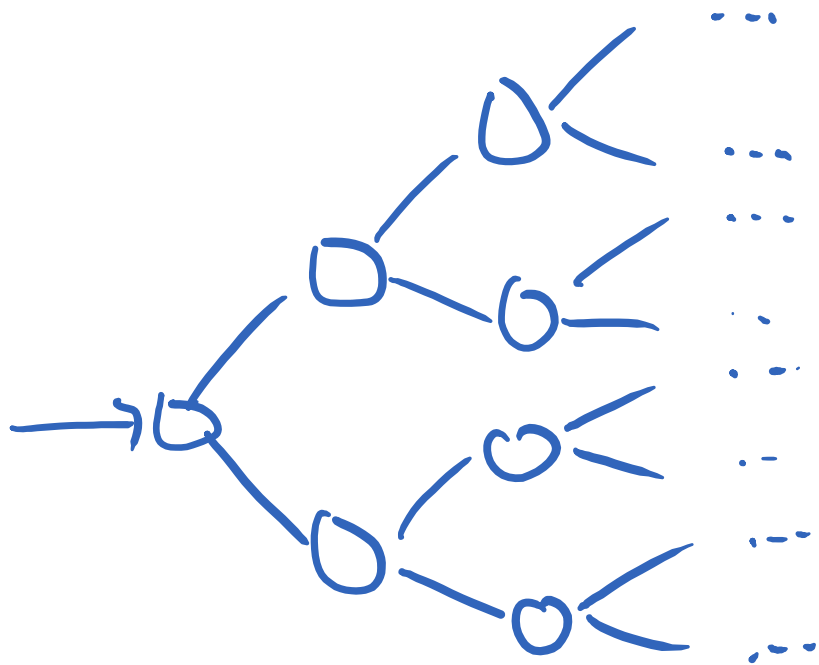
“

Because nature is not classical, dammit, and if you want to make a simulation of nature – you'd better make it quantum mechanical!

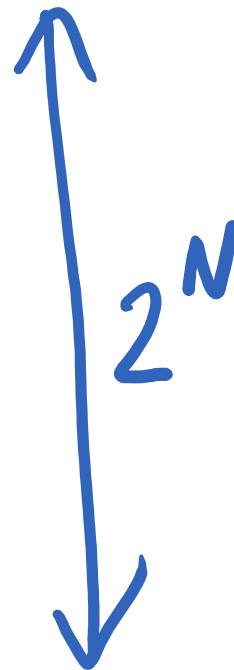
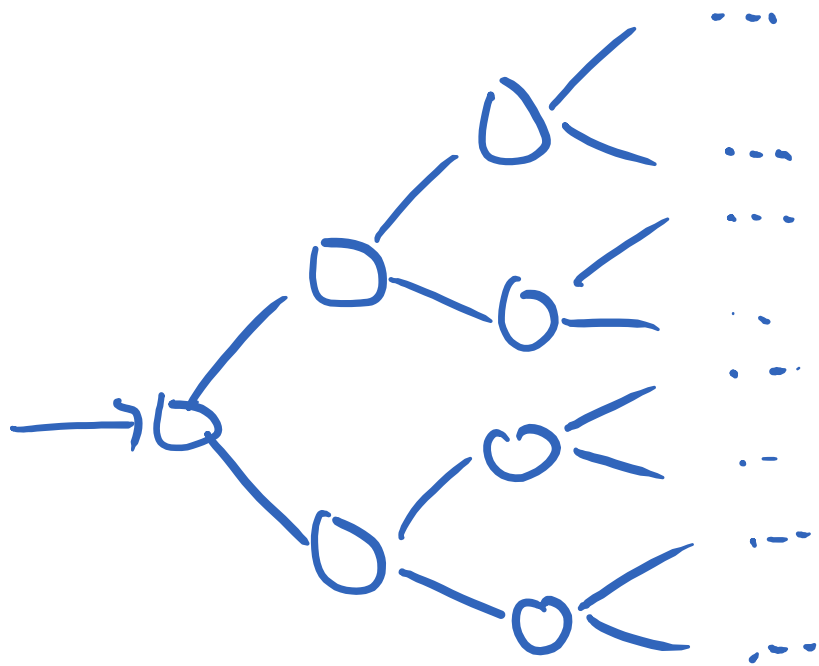
”

R. P. Feynman

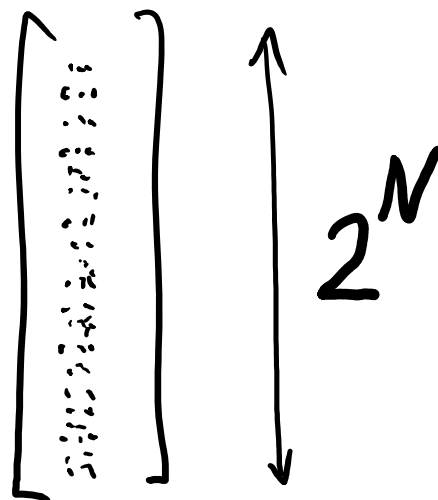


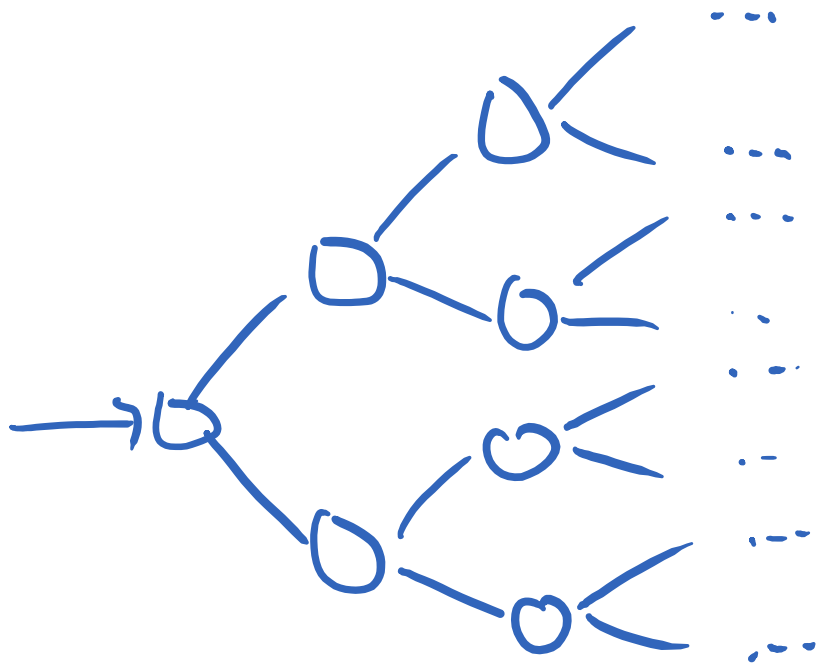


superpozície
a vlny?

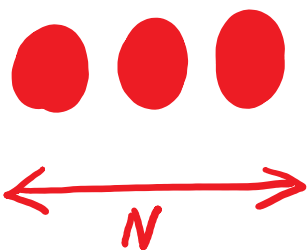


N qubitov





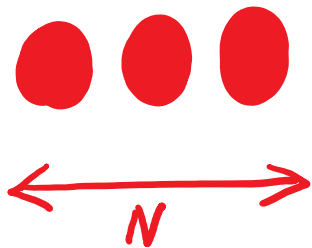
2^N



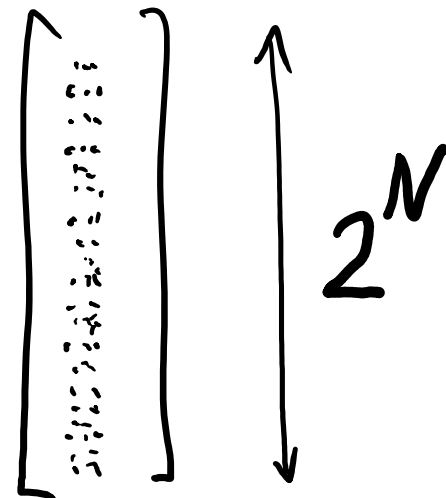
N qubitov

2^N

→ inicializácia

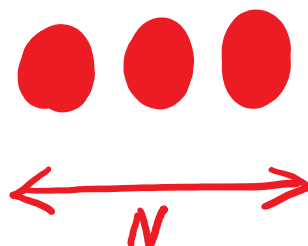


N qubitov



→ inicializácia

lokálne transformácie 

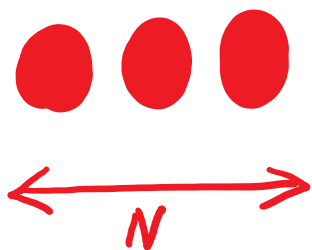

N qubitov

$$\begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix} \updownarrow 2^N$$

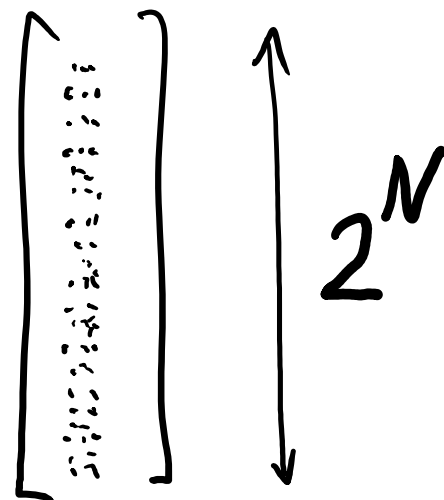
→ inicializácia

lokálne transformácie 

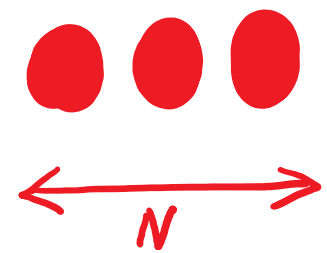
oprava chýb  → 



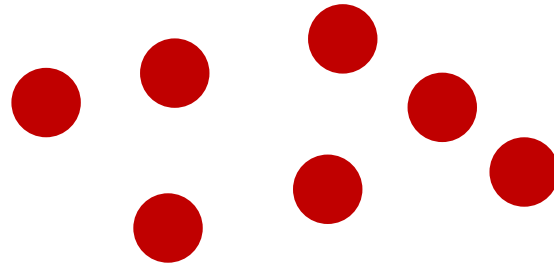
N qubitov



- inicializácia
- lokálne transformácie 
- oprava chýb 
- ← meranie


N qubitov

$$\begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix} \updownarrow 2^N$$



m-i-c-r-o-s-c-o-p-i-c r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c r-u-l-e-
s m-i-c-r-o-s-c-o-p-i-c r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c r-u-
l-e-s m-i-c-r-o-s-c-o-p-i-c r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c
r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c r-u-l-e-s m-i-c-r-o-s-c-o-p-i-
c r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c r-u-l-e-s m-i-c-r-o-s-c-o-p-

MACROSCOPIC PROPERTIES

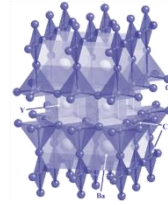
m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-
s m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c-r-u-
l-e-s m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c-
r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-s m-i-c-r-o-s-c-o-p-i-
c-r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-s m-i-c-r-o-s-c-o-p-i-c-r-u-l-e-s m-i-c-r-o-s-c-o-p-

density, heat capacity, magnetization, correlations, spectrum, ...

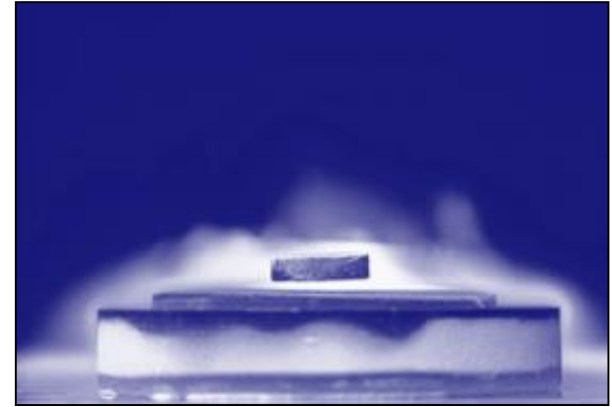
High T_c superconductors



Bednorz, Mueller
1987



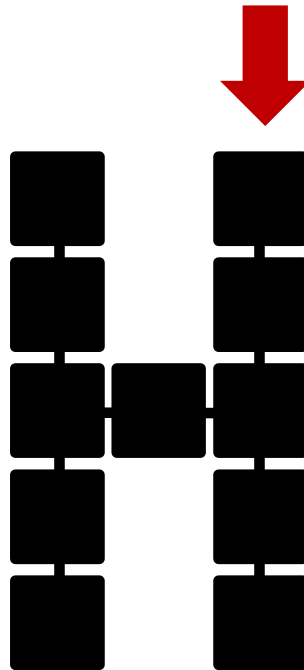
[Cornell]



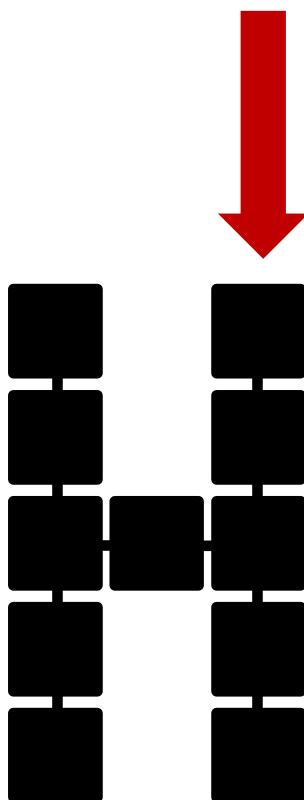
[D. Parker, U. Birmingham]



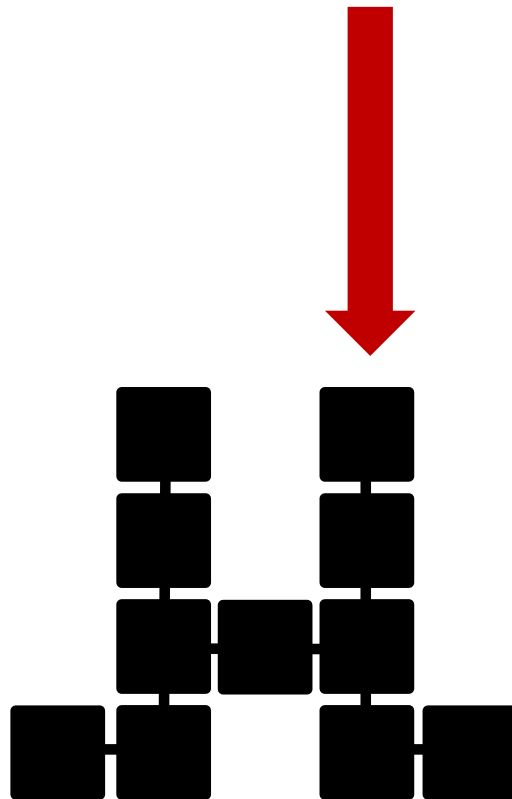
OPTIMIZATION



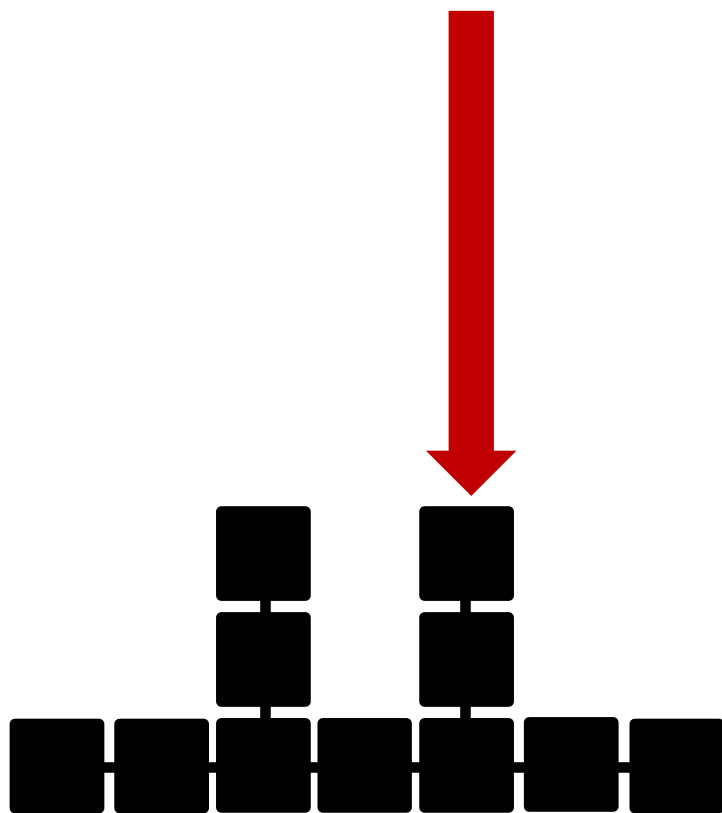
OPTIMIZATION



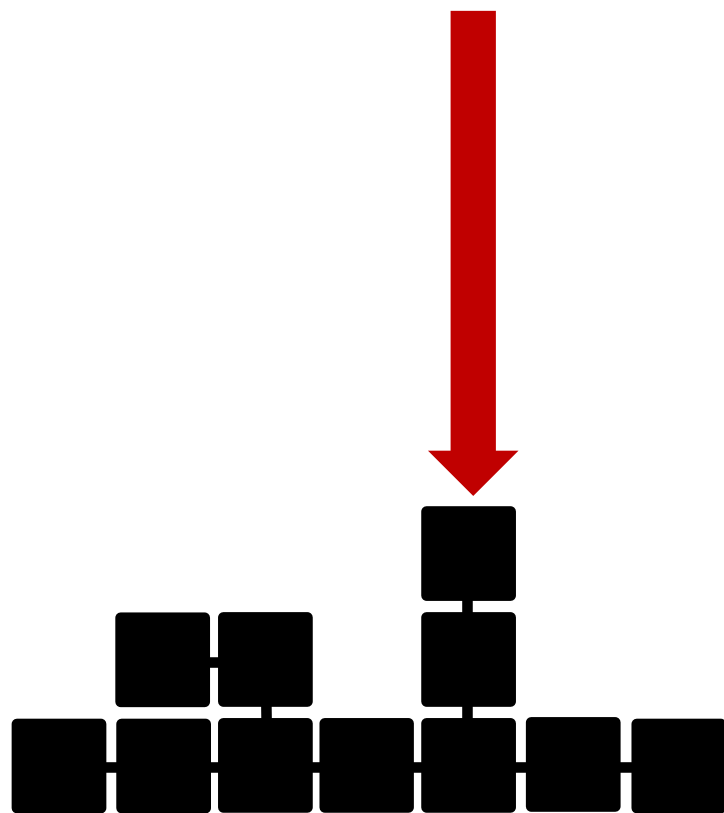
OPTIMIZATION



OPTIMIZATION

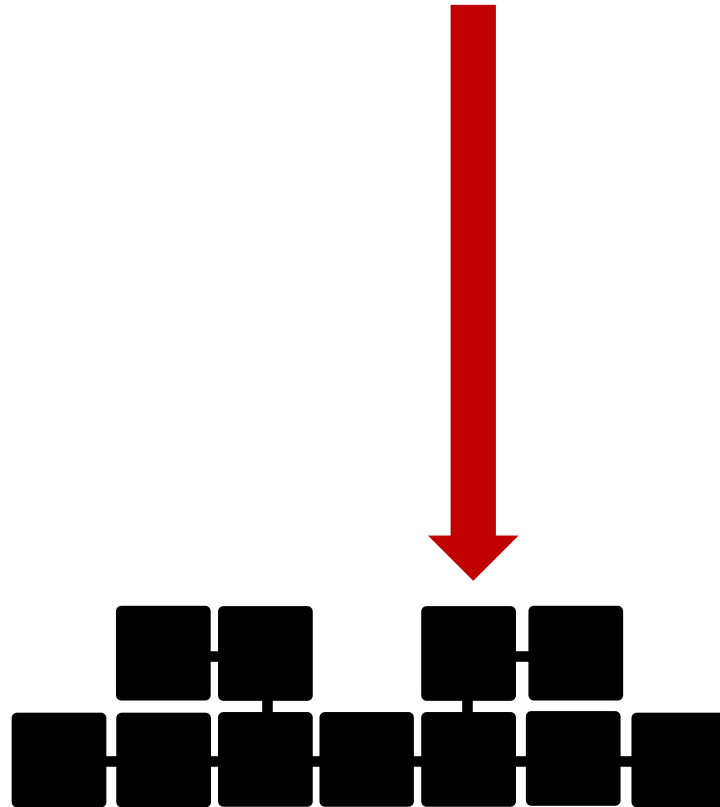


OPTIMIZATION

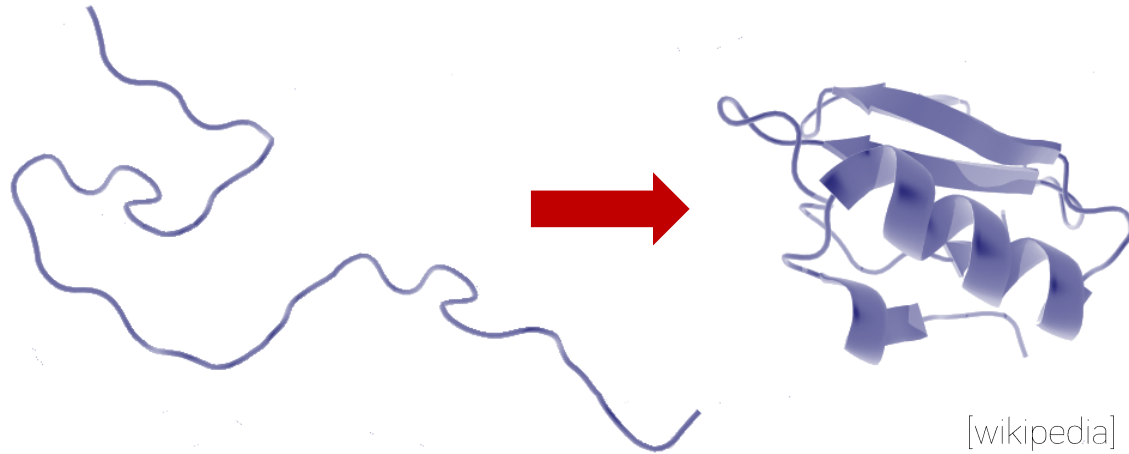


OPTIMIZATION

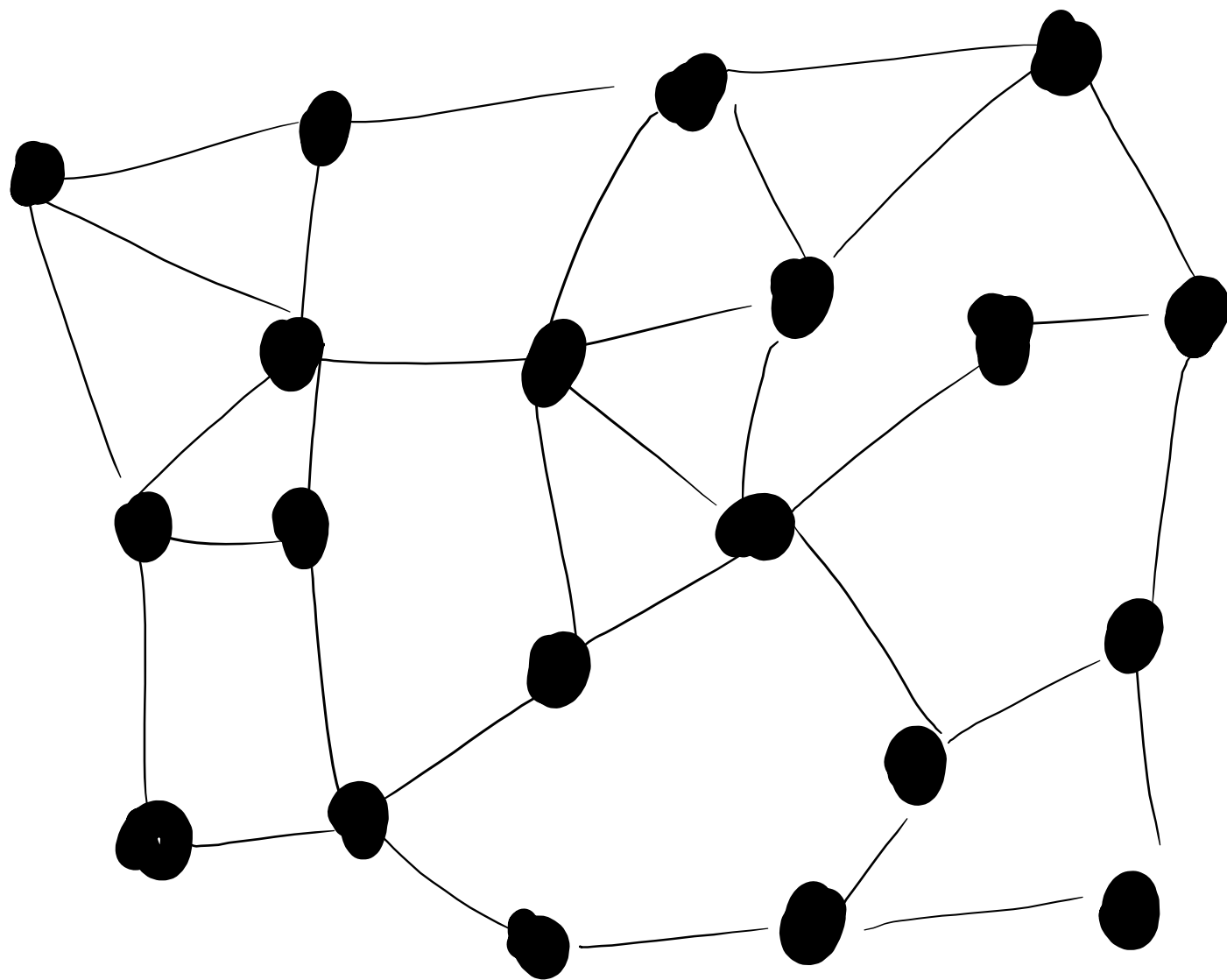
finding the (best) solution

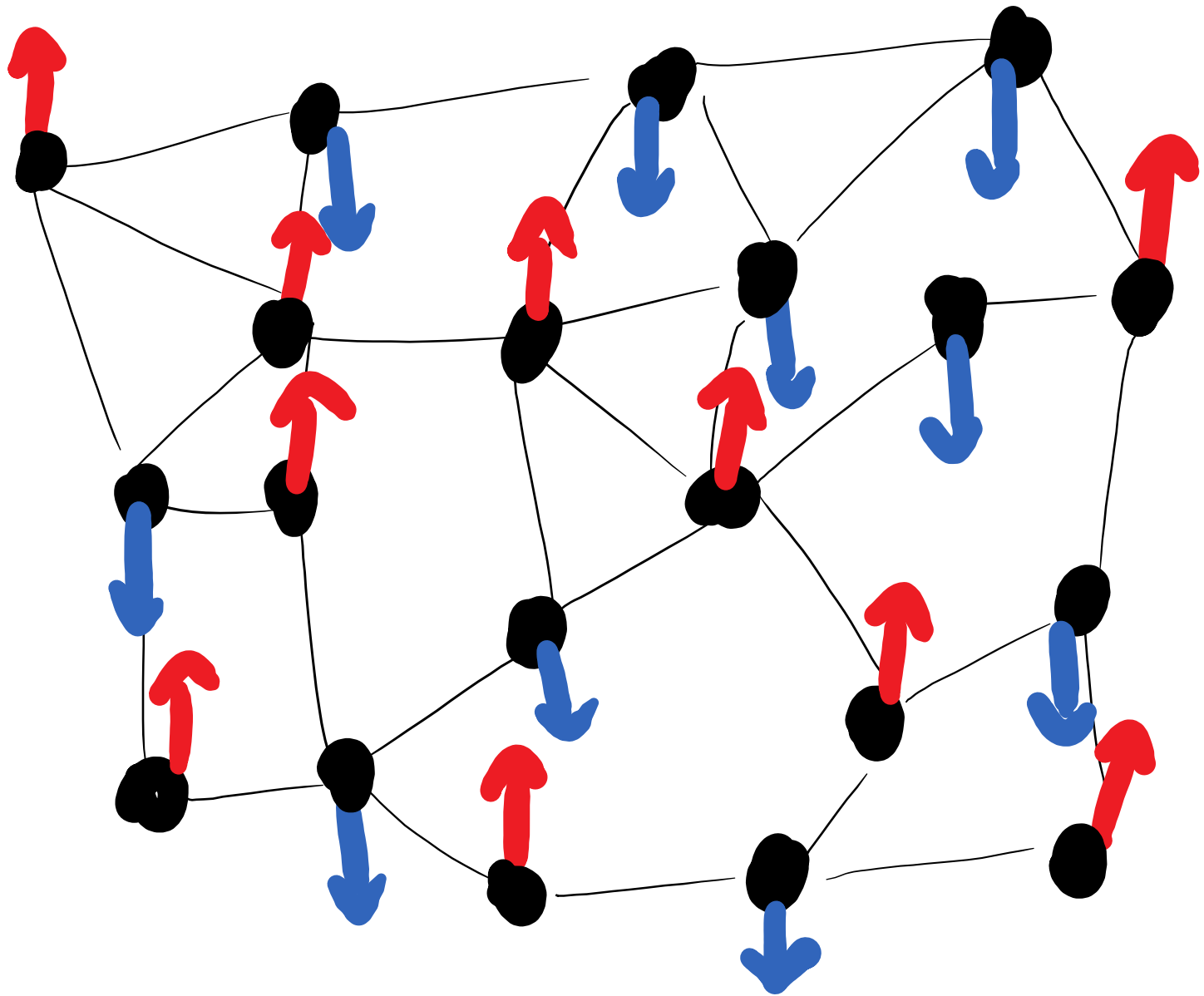


OPTIMIZATION

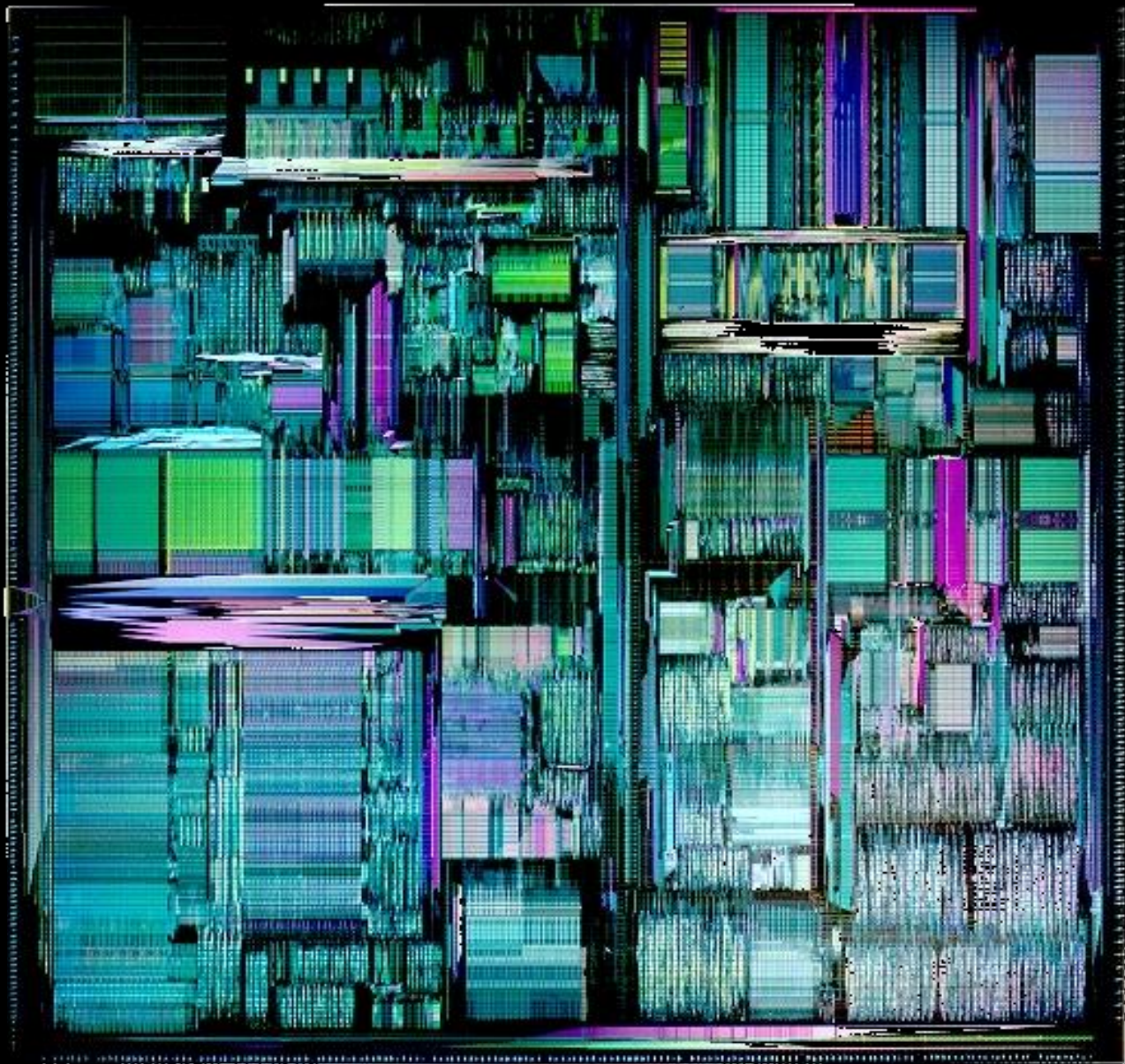


protein folding

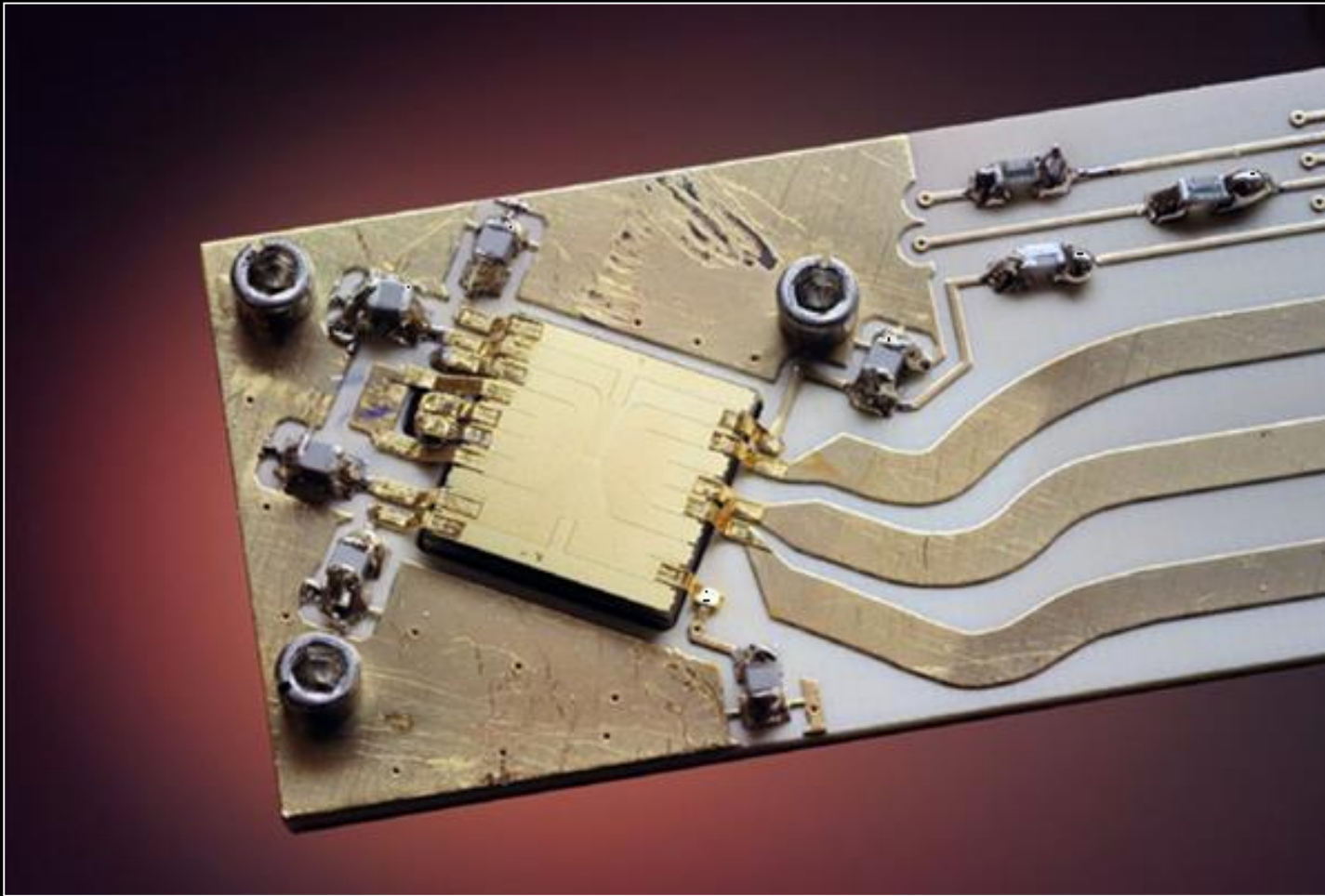




■ 2D Ising: NP-complete ($\pm J$, external field) [Barahona84]



[1995 Pentium Pro, www.tayloredge.com/museum]



[NIST gold ion trap on aluminum-nitride backing, Y.Colombe/NIST]



[Dwave 2 computer, www.dwavesys.com]

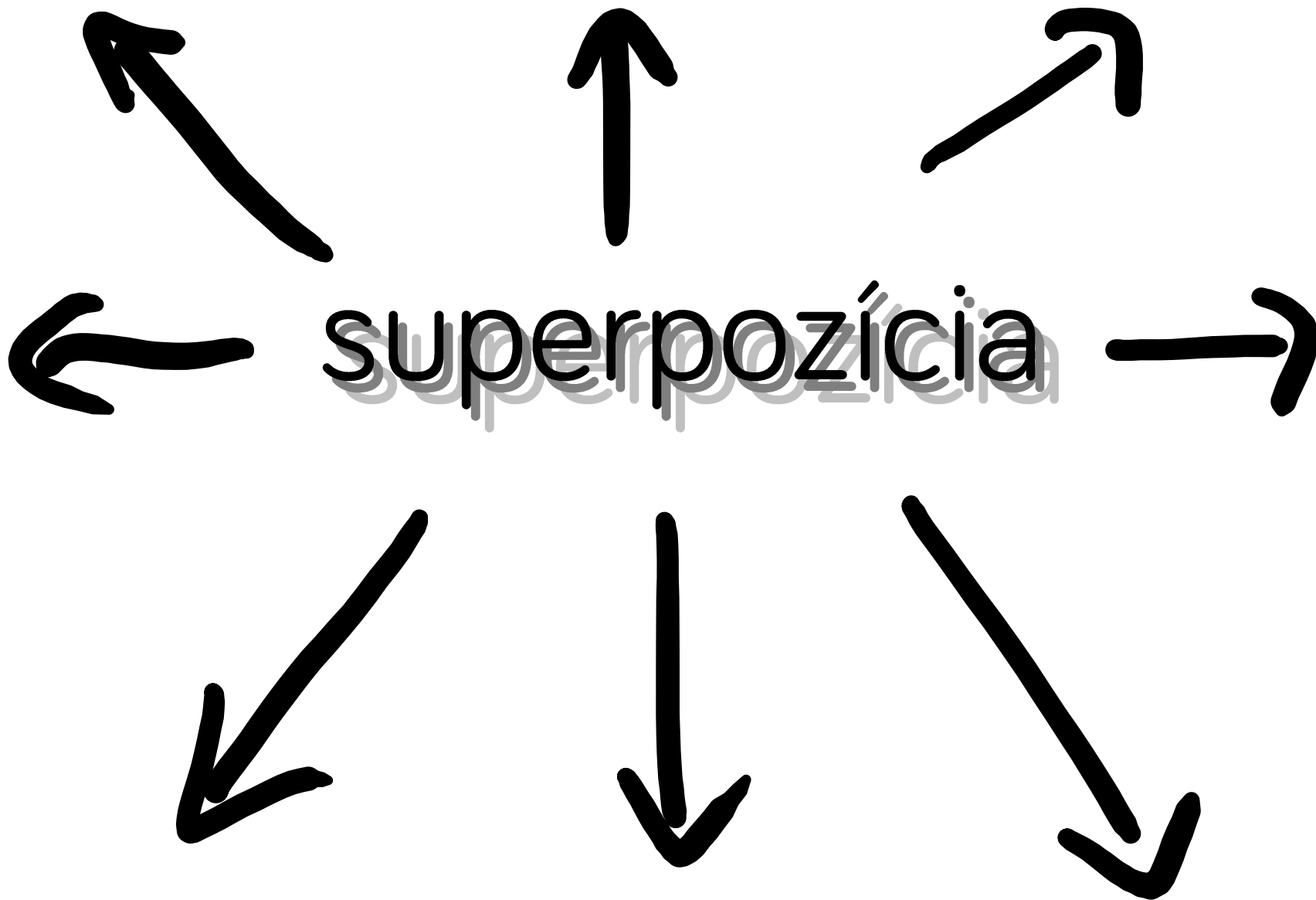
← pozícia



pozícia



pozícia



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superposição

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superpozícia
meranie

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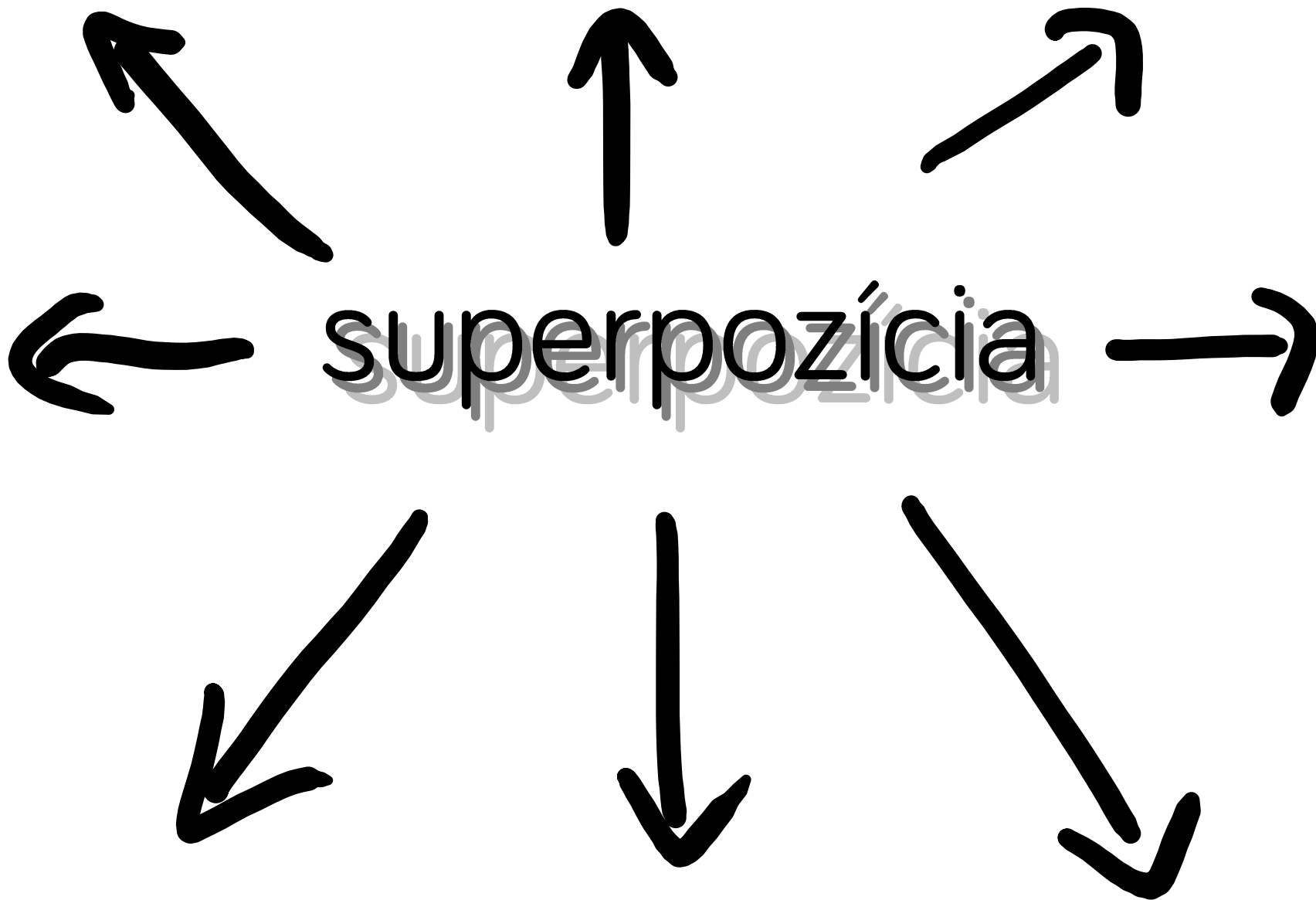


superpozícia
meranie



superpozícia
meranie







superpozícia



superpozícia

transformácia



superpozícia

transformácia



superpozícia

transformácia



superpozícia

transformácia



superpozícia

transformácia



superpozícia

transformácia

superpozícia

transformácia



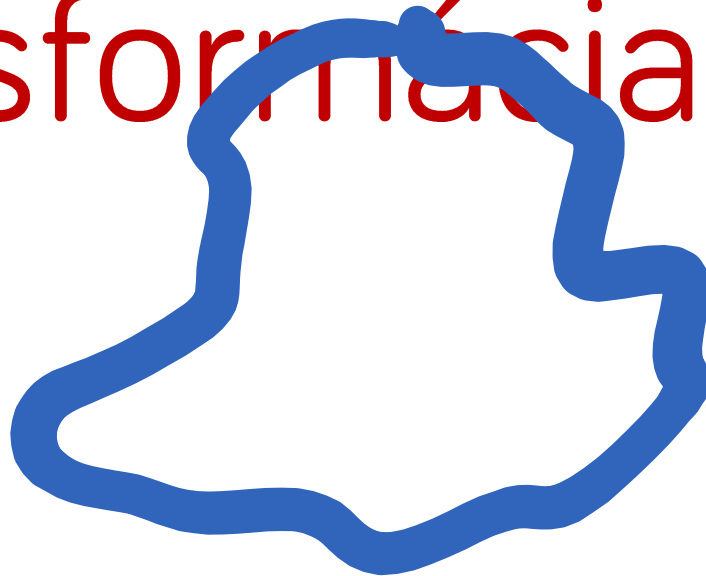
superpozícia

transformácia



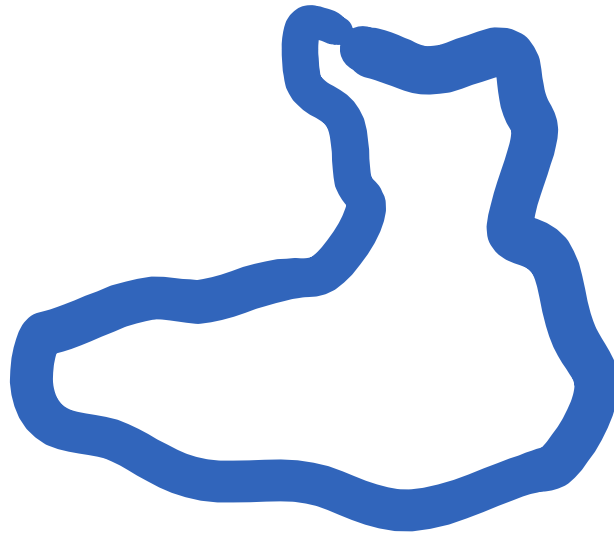
superpozícia

transformácia



superpozícia

transformácia



superpozícia

transformácia

meranie



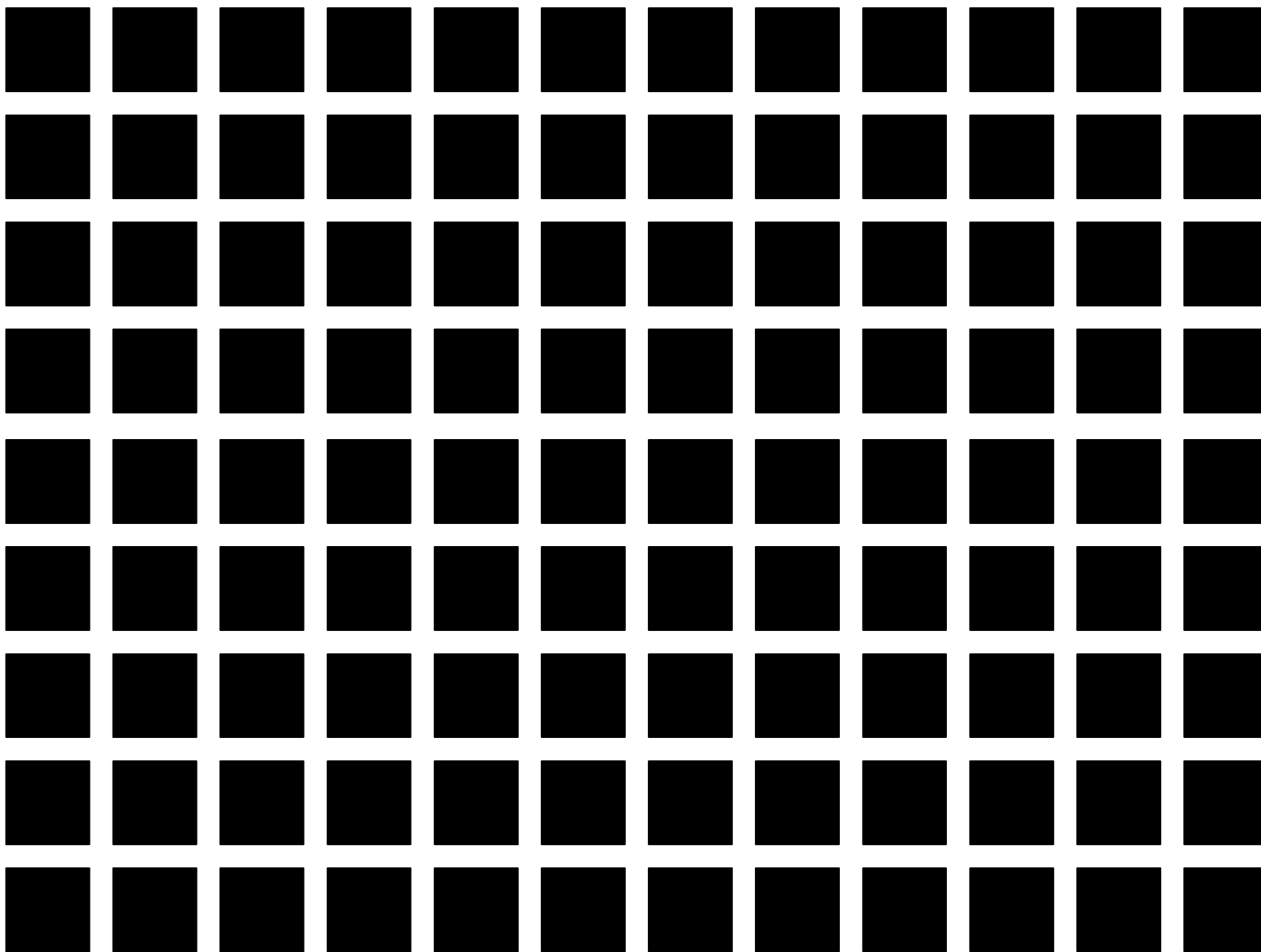
ALGORITMUS

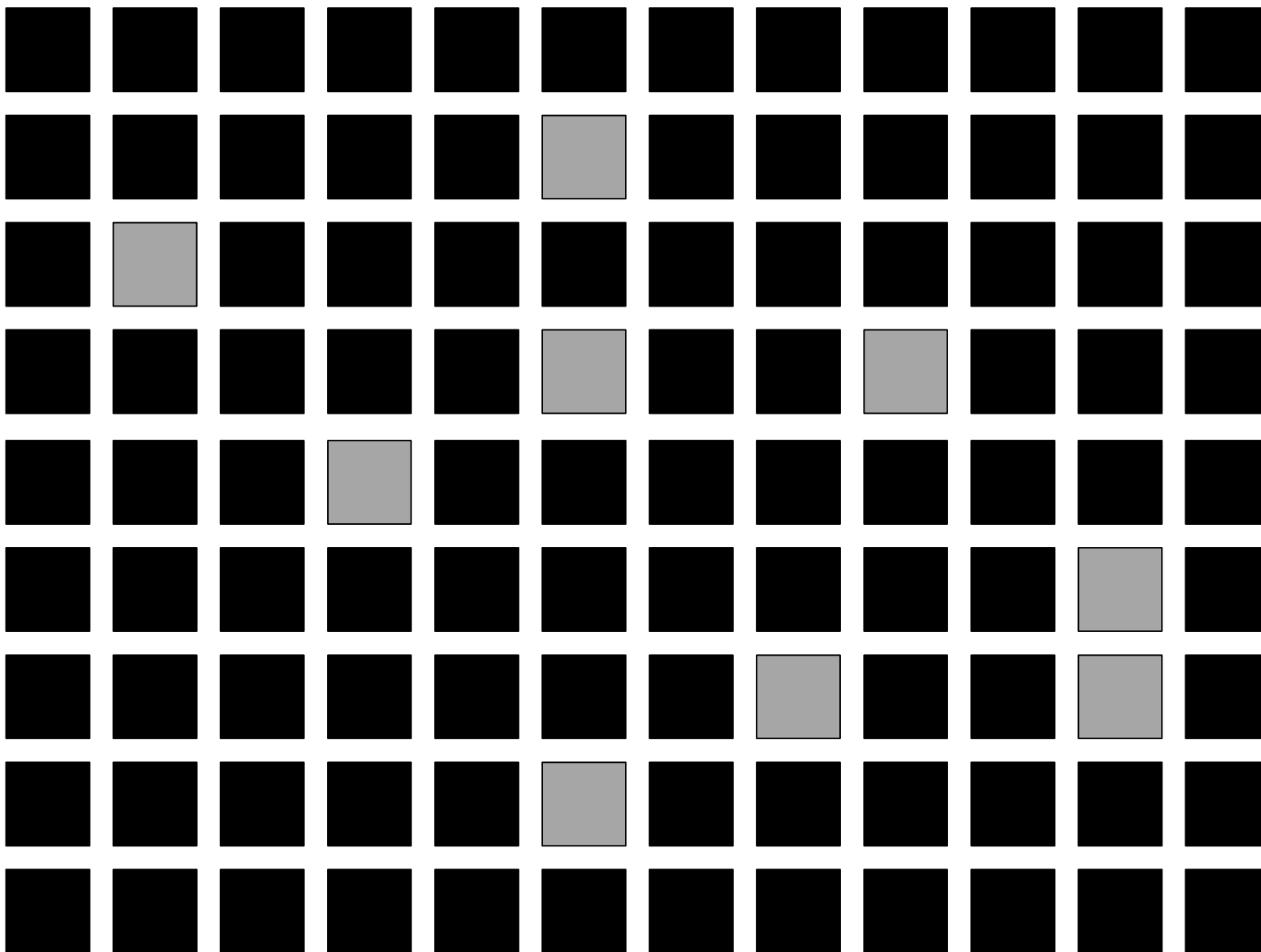
superpozícia

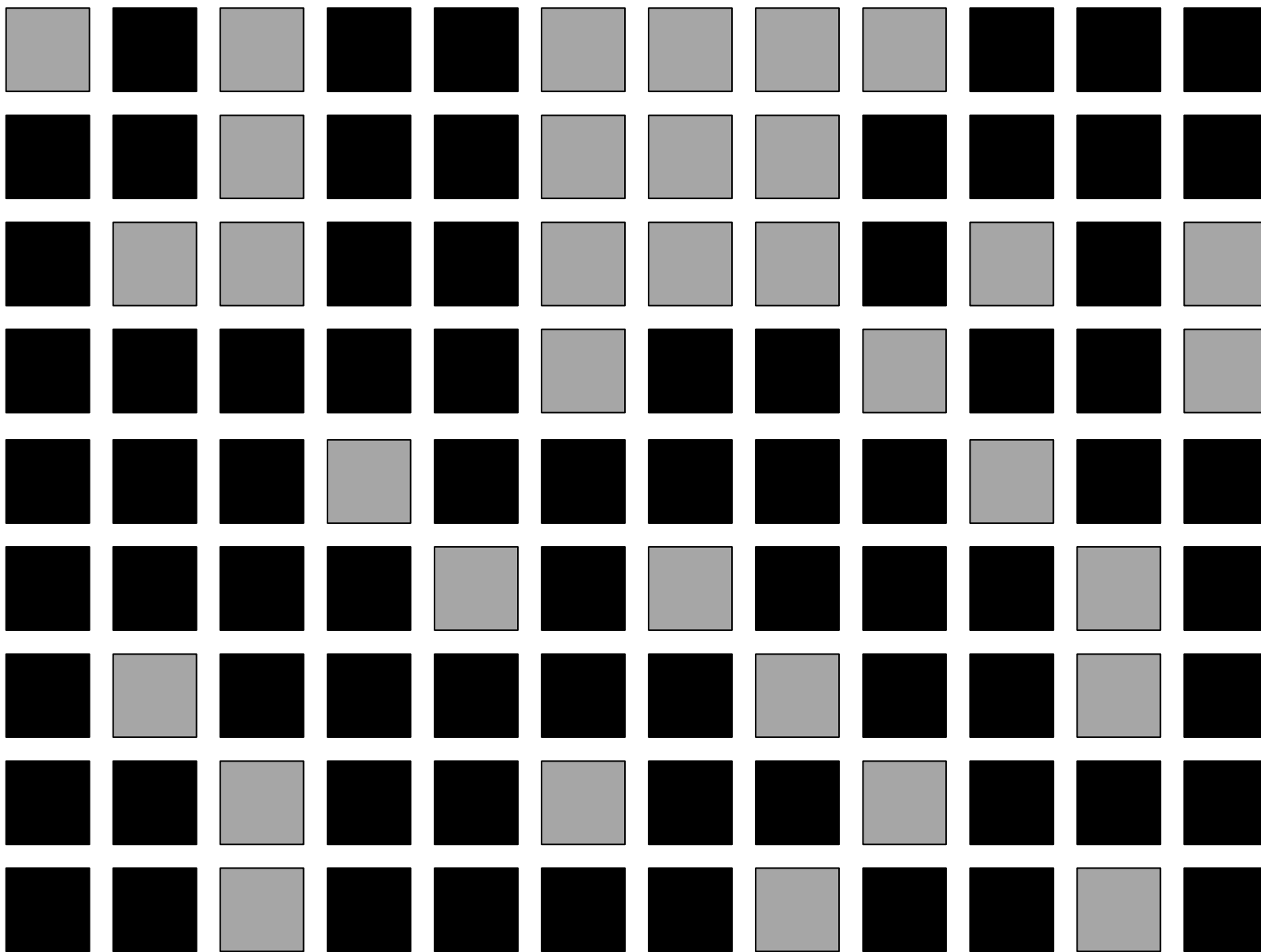
transformácia

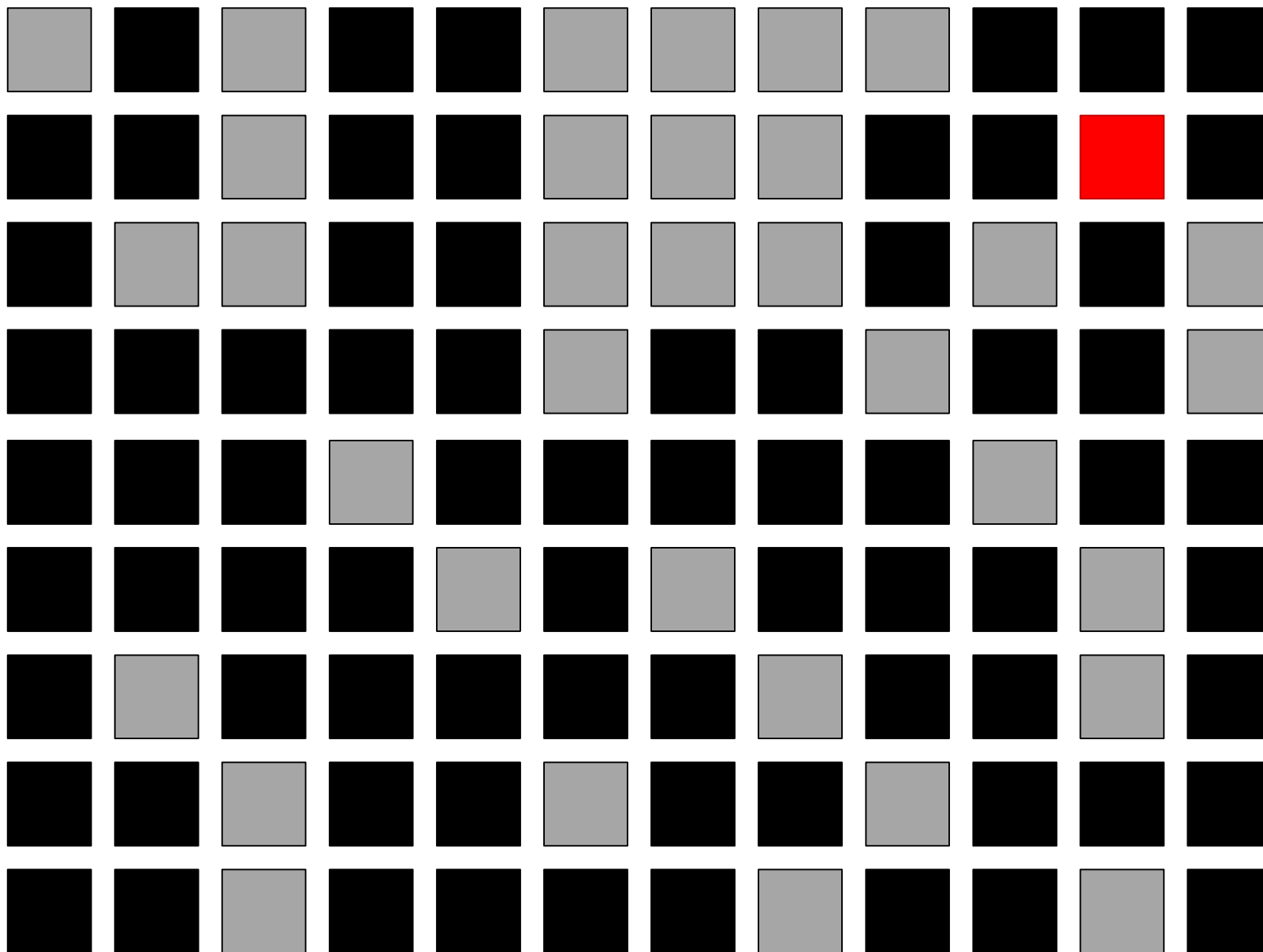
meranie

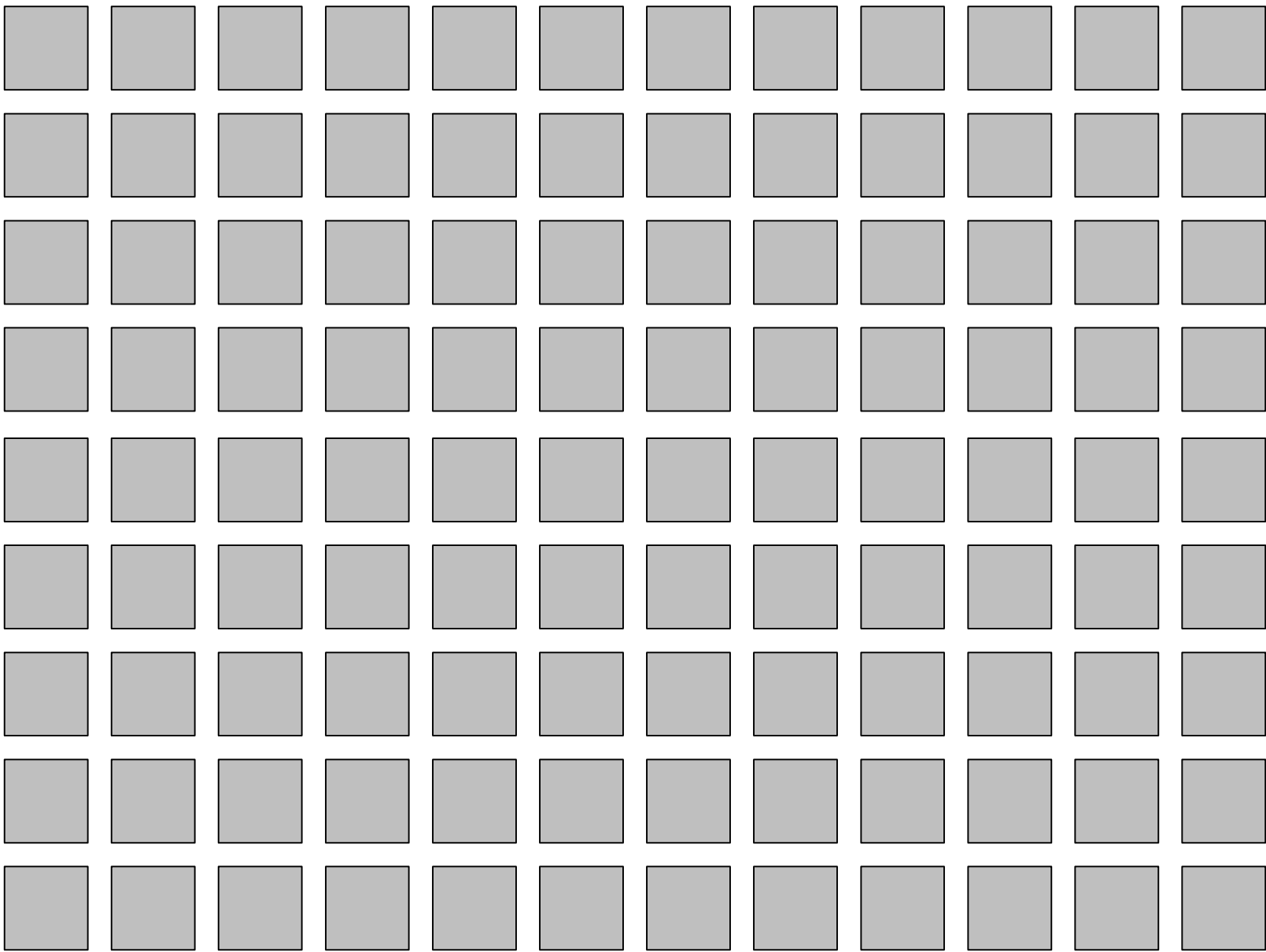


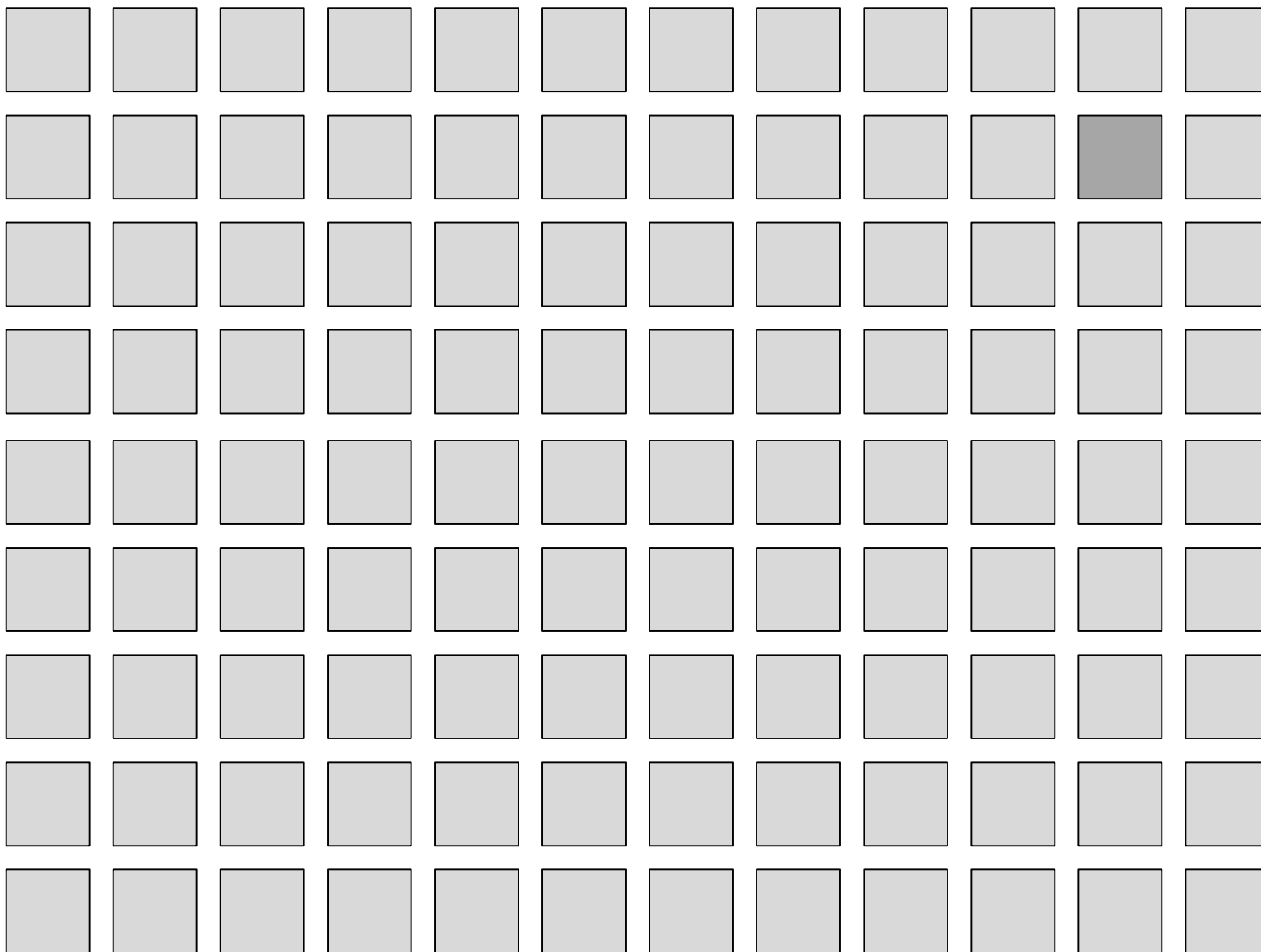


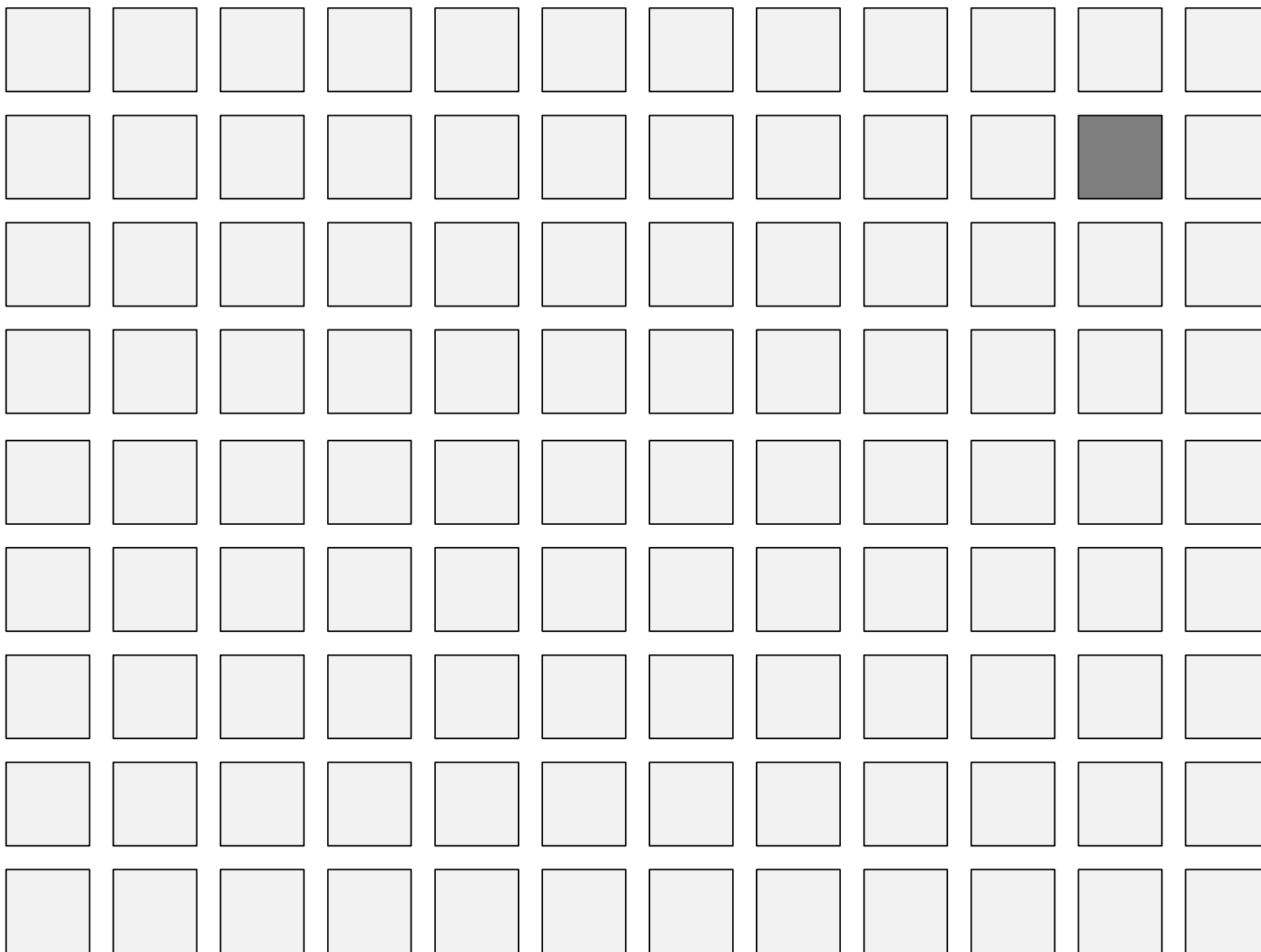


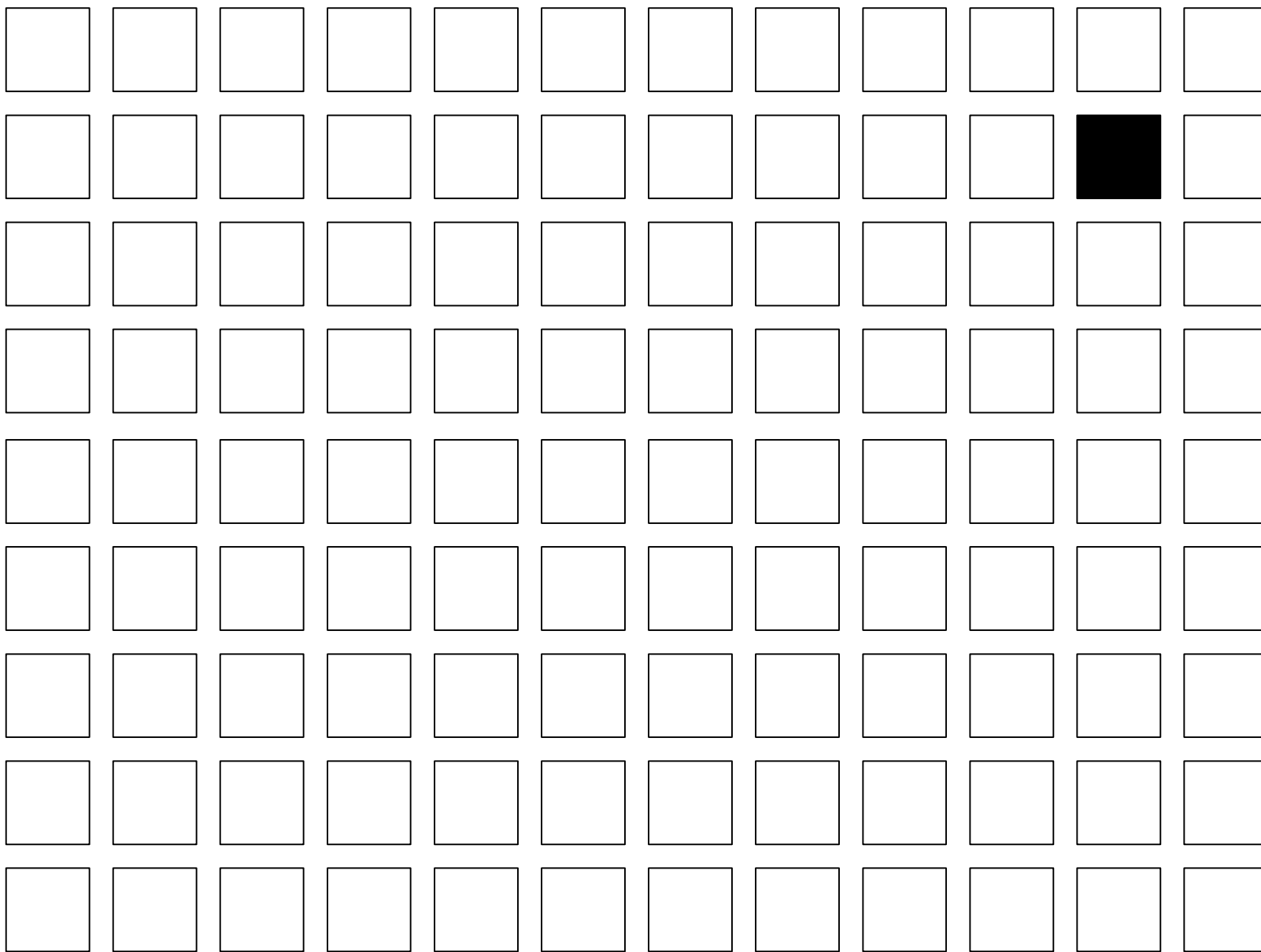


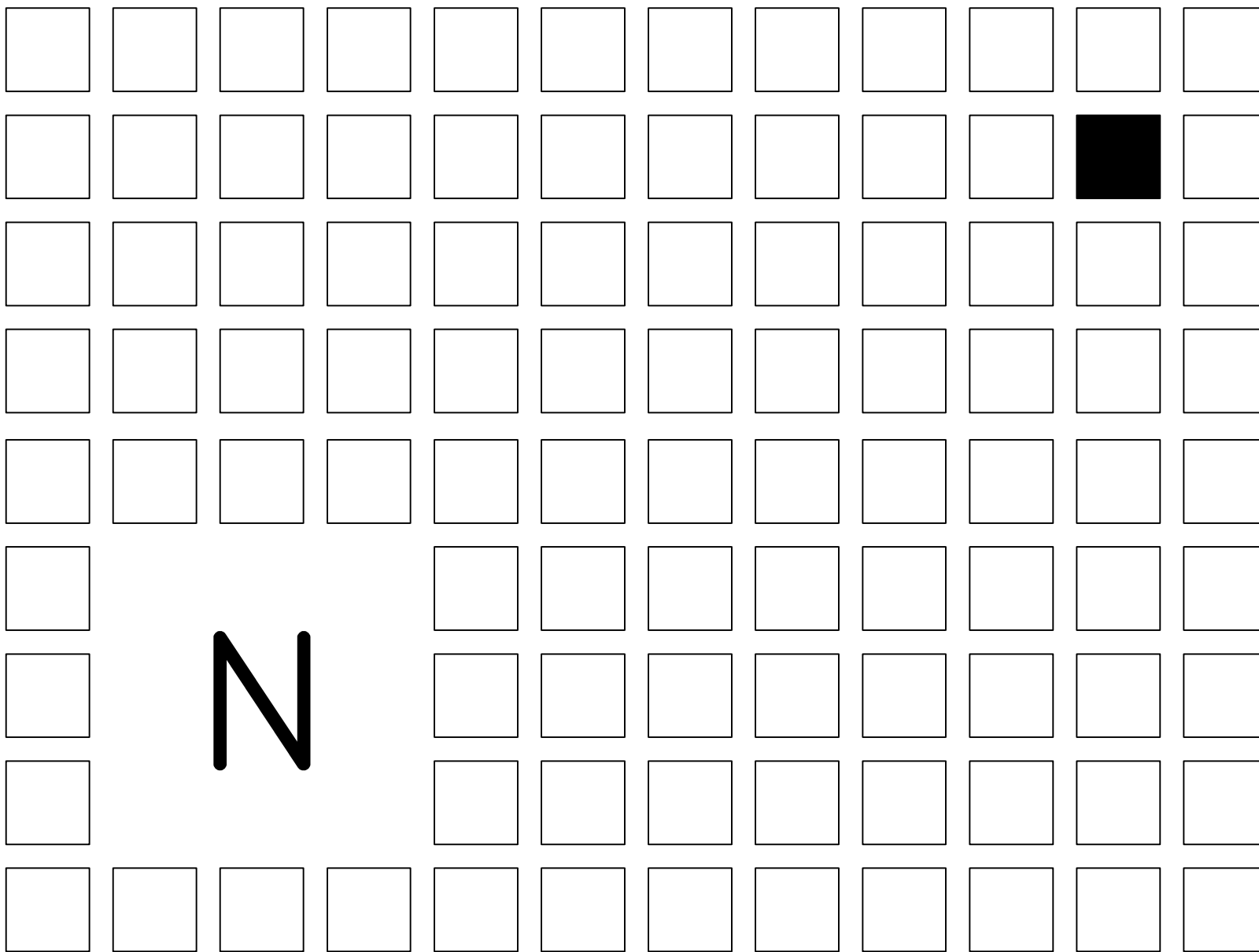




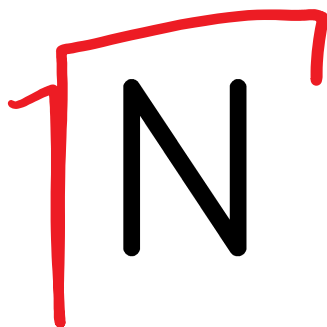








Groverov algoritmus



Groverov algoritmus

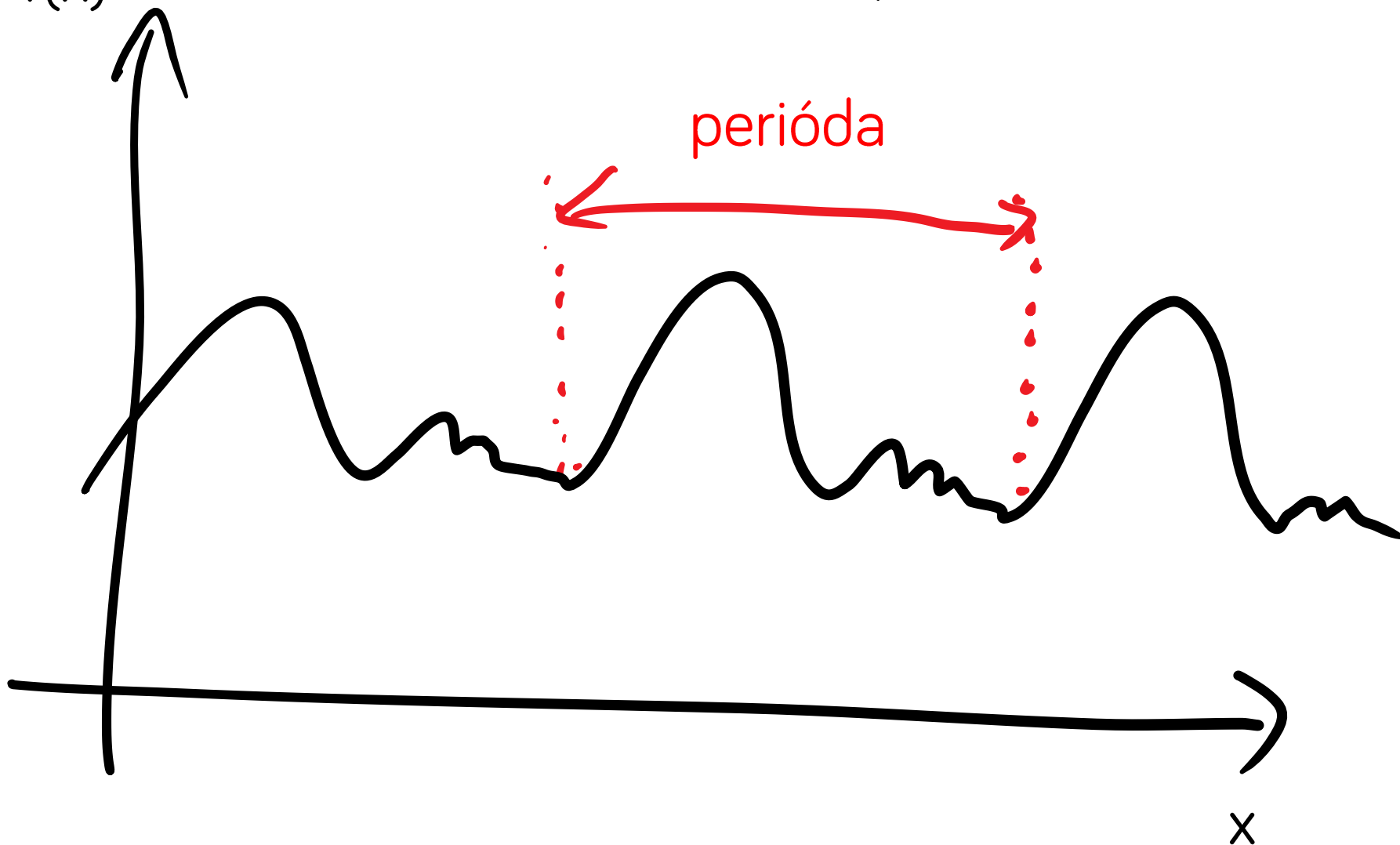
N

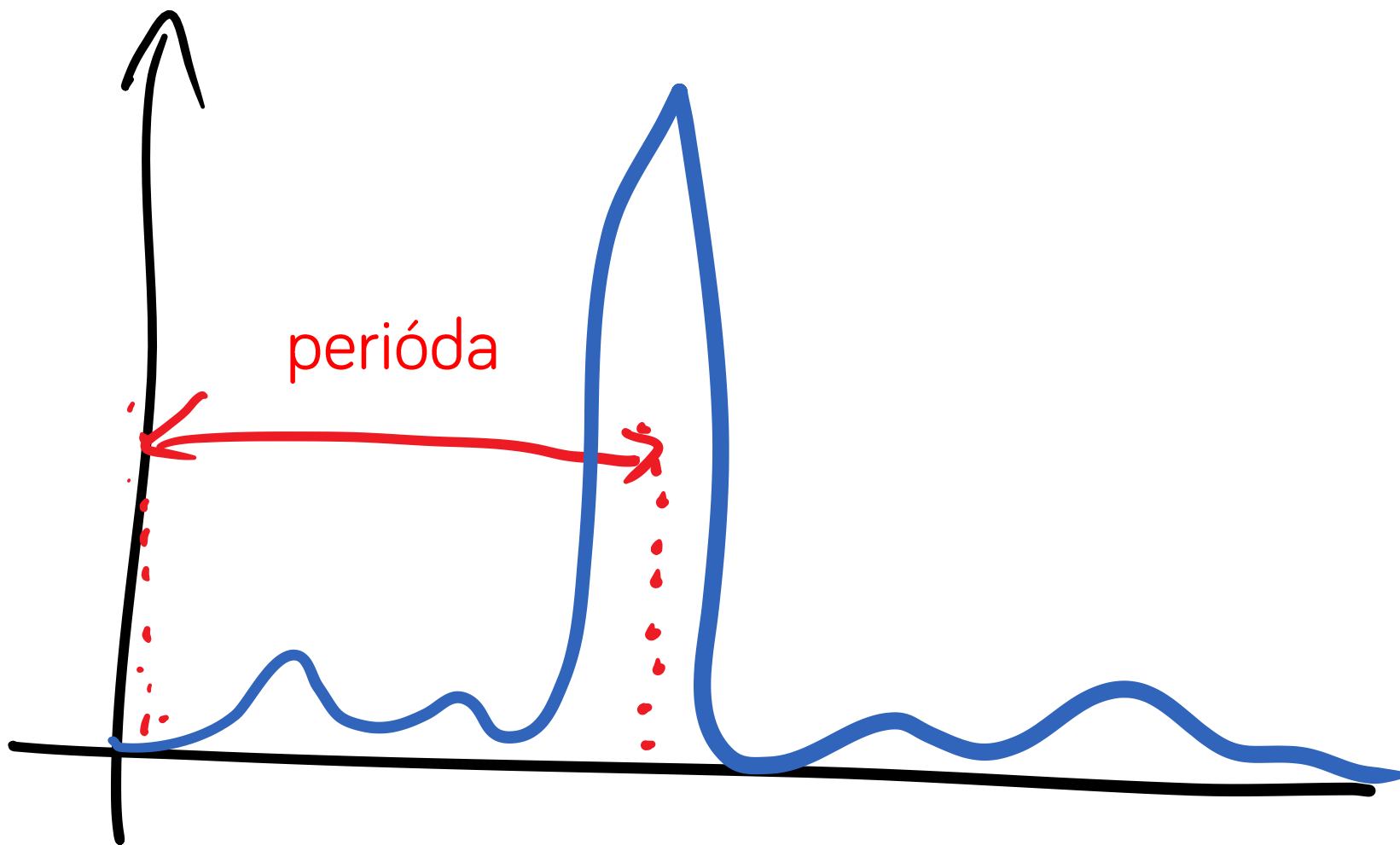
NEDÁ SA
to lepšie!

$f(x)$

periodická funkcia

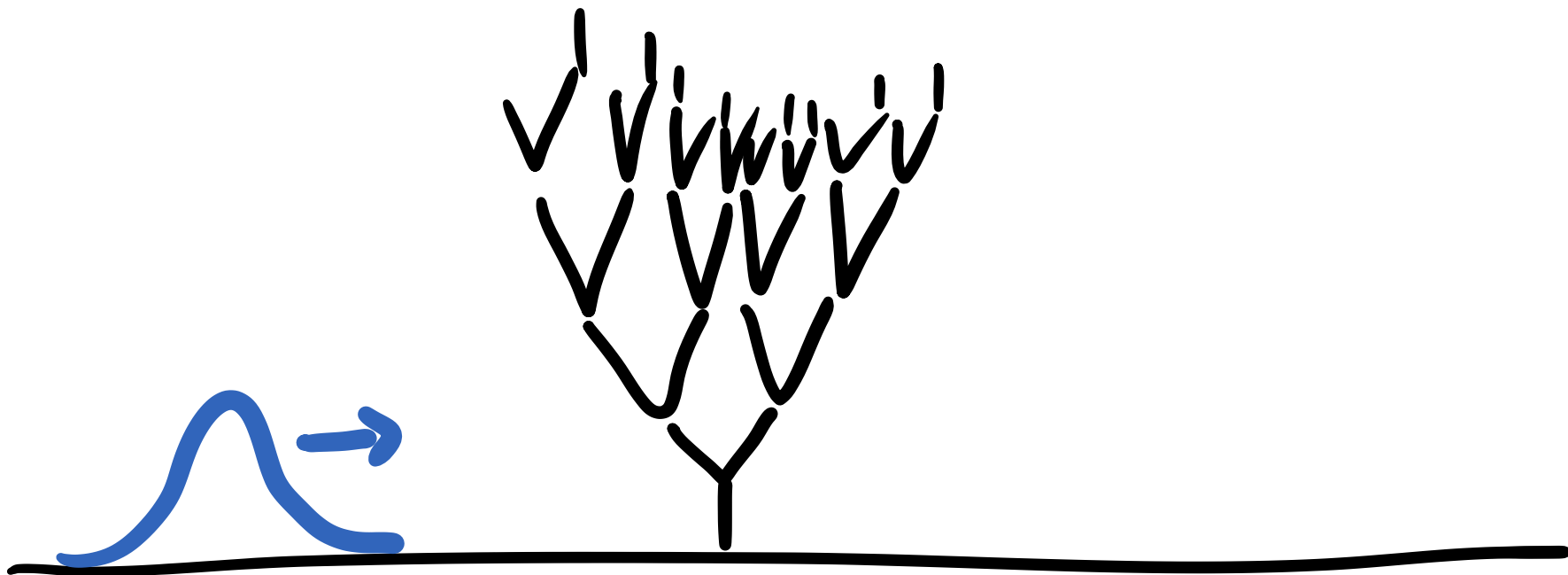
perióda

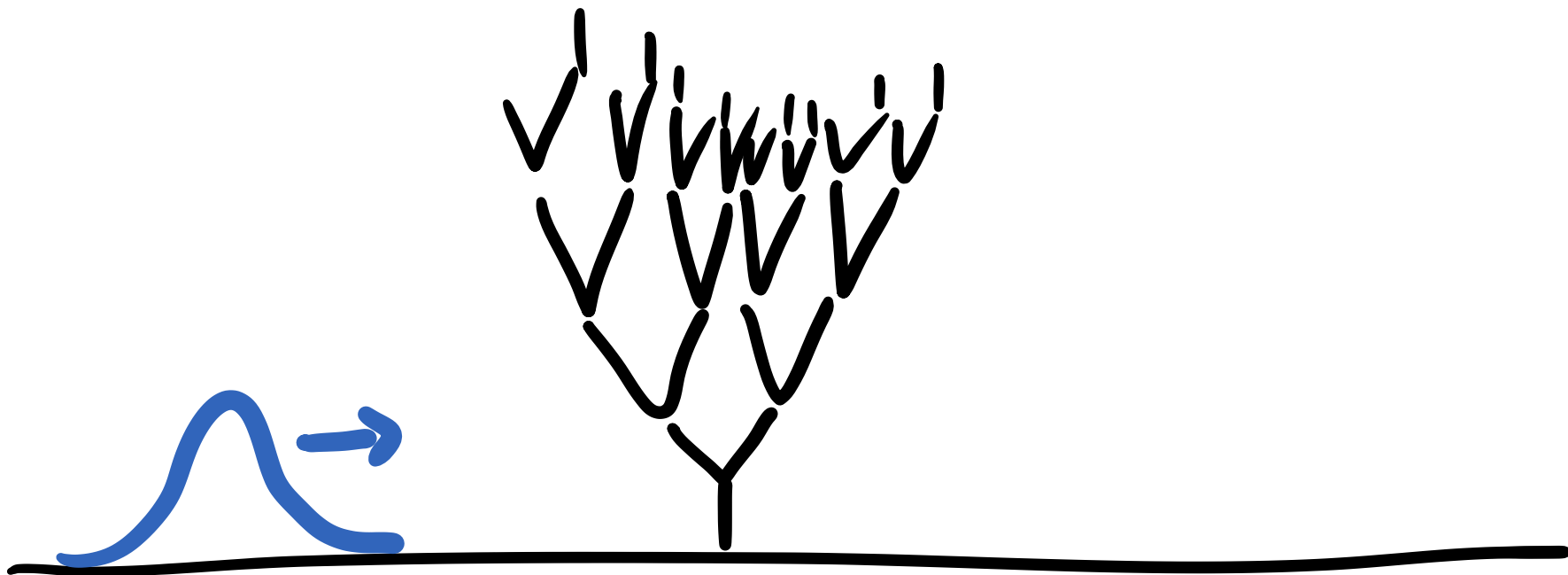


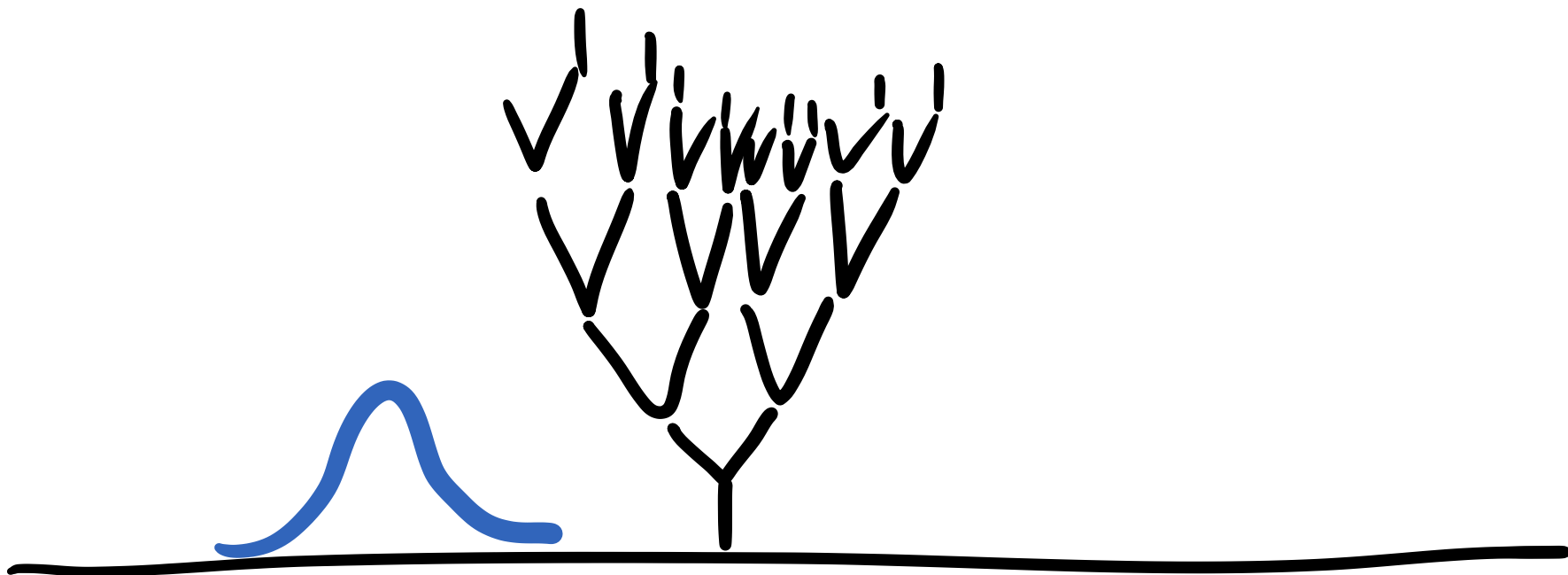


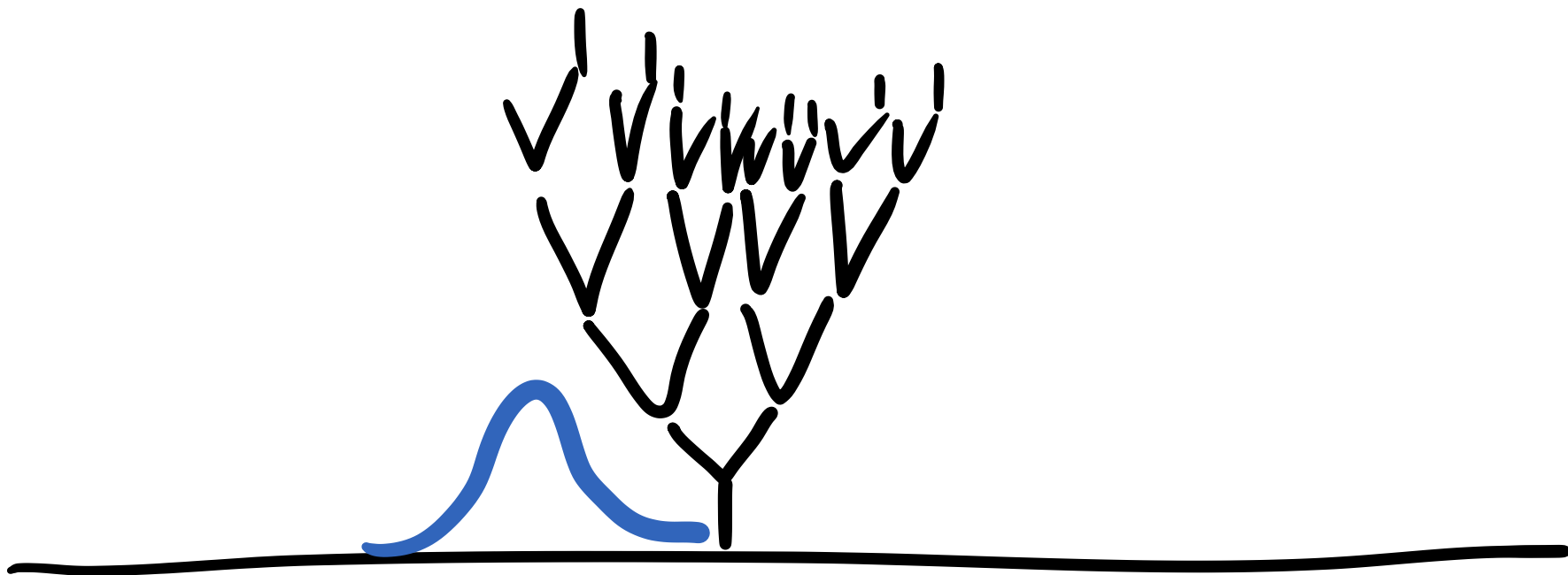
Fourierova transformácia, Shorov algoritmus

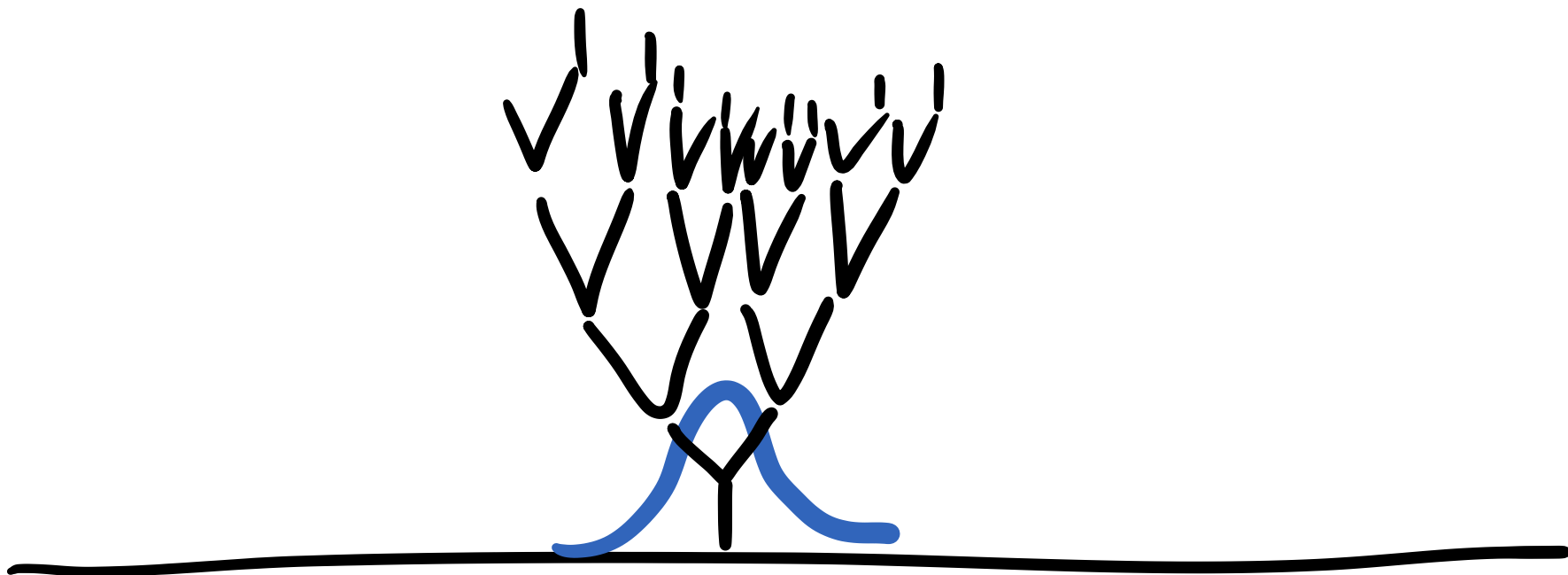
Hra: idem ja, ideš ty...
Má prvý vítaznú stratégiu?

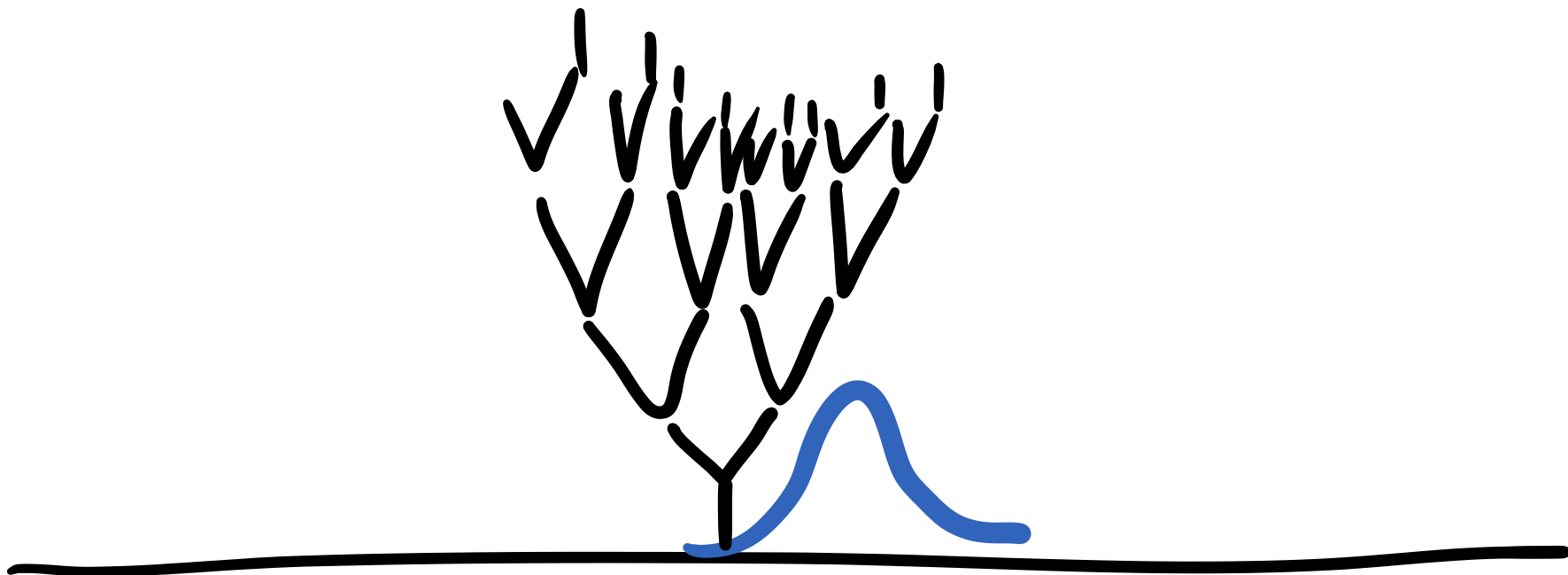


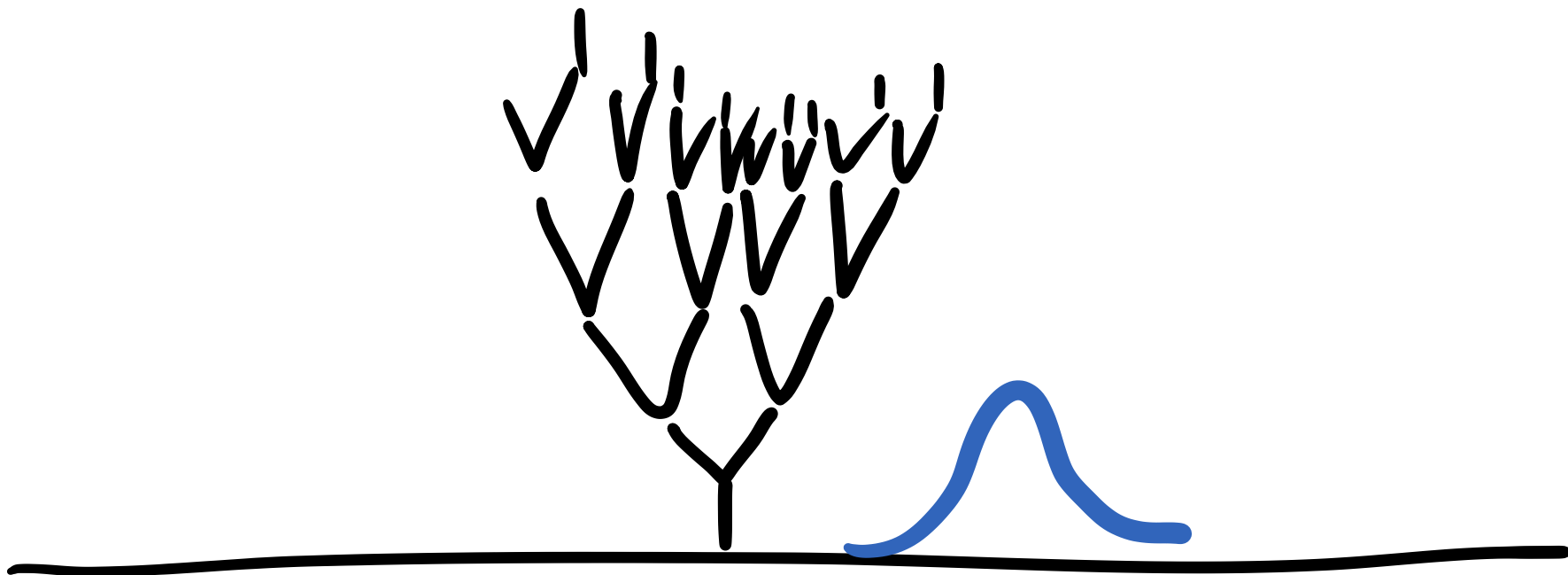


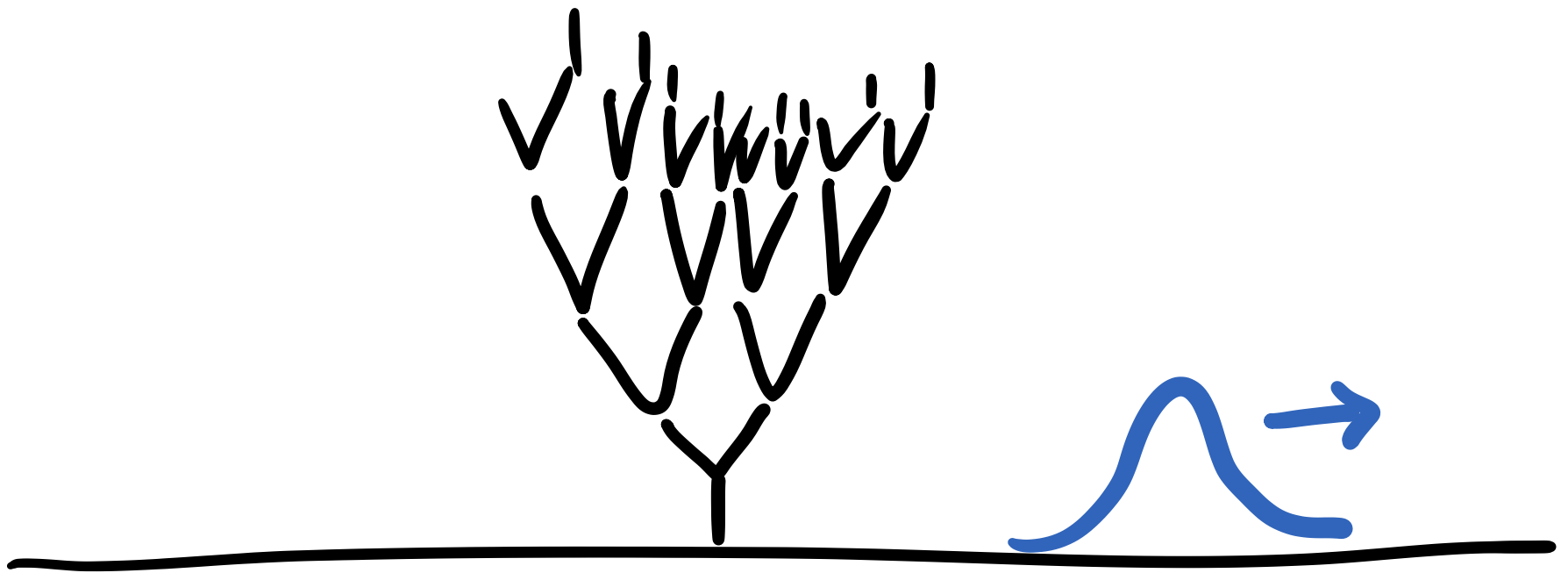


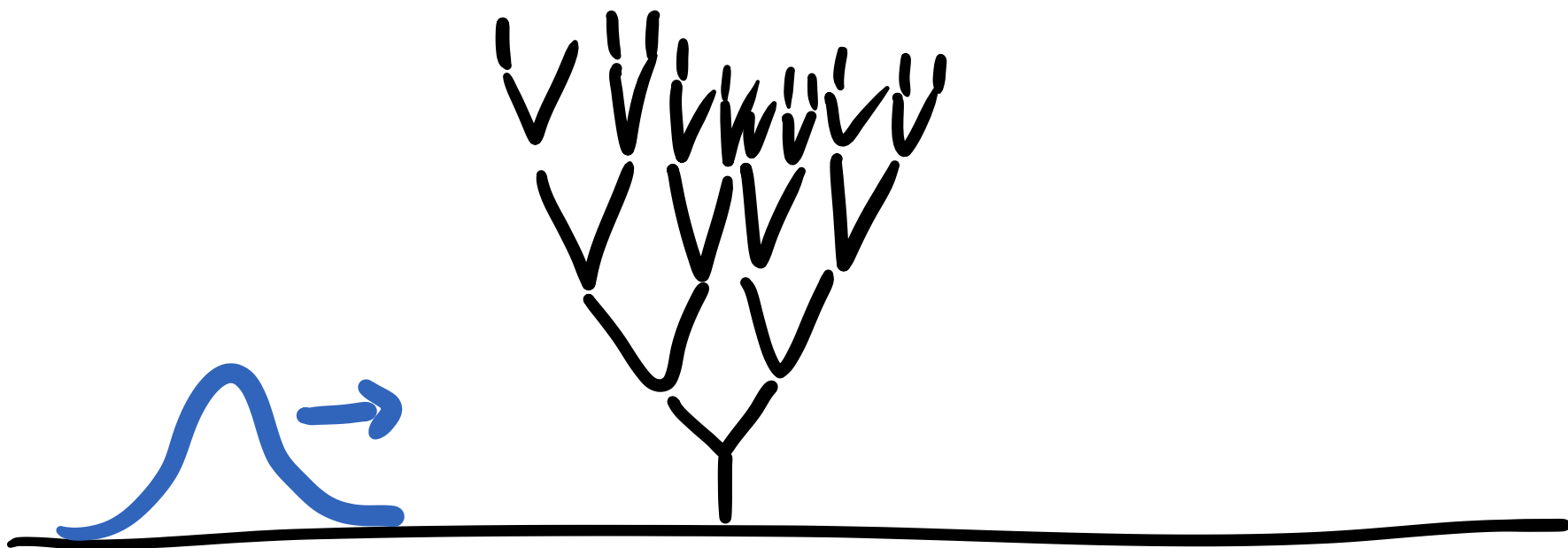


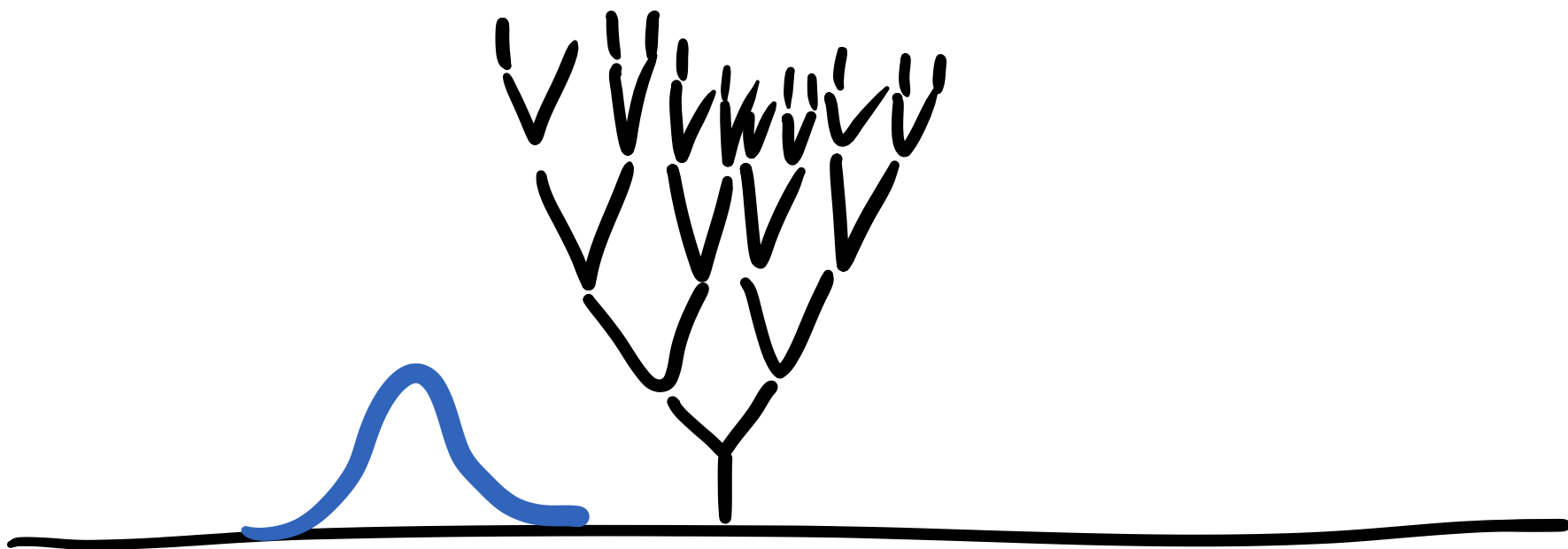


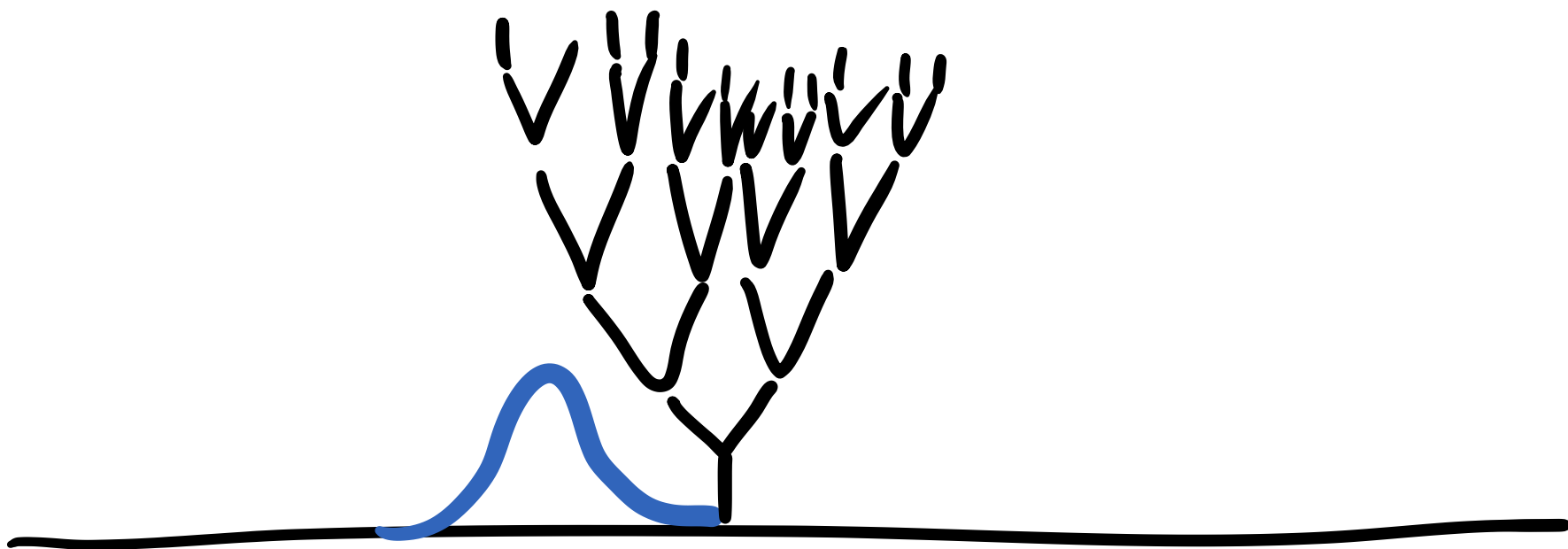


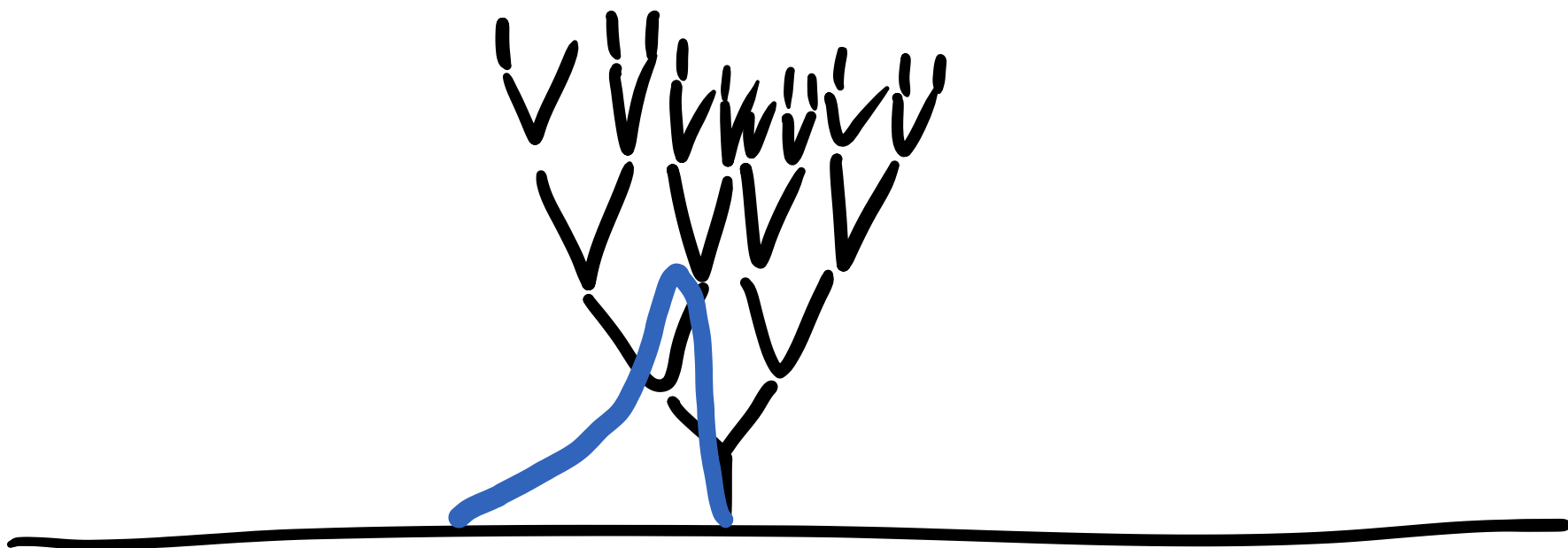


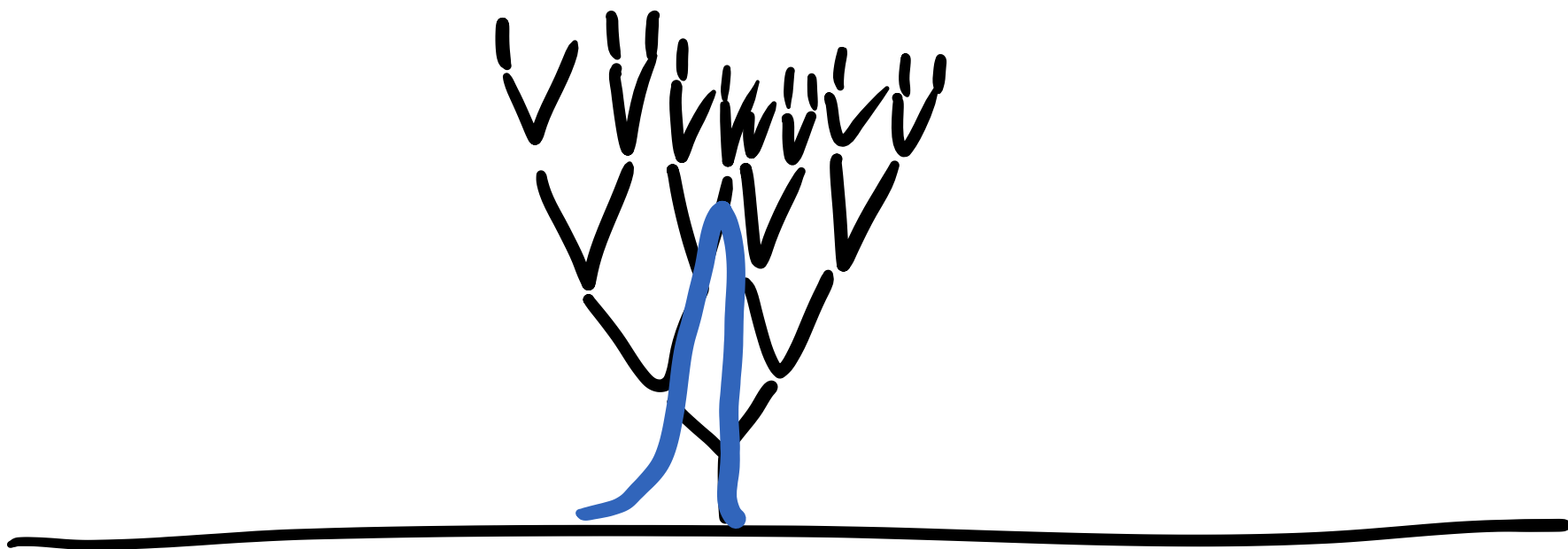


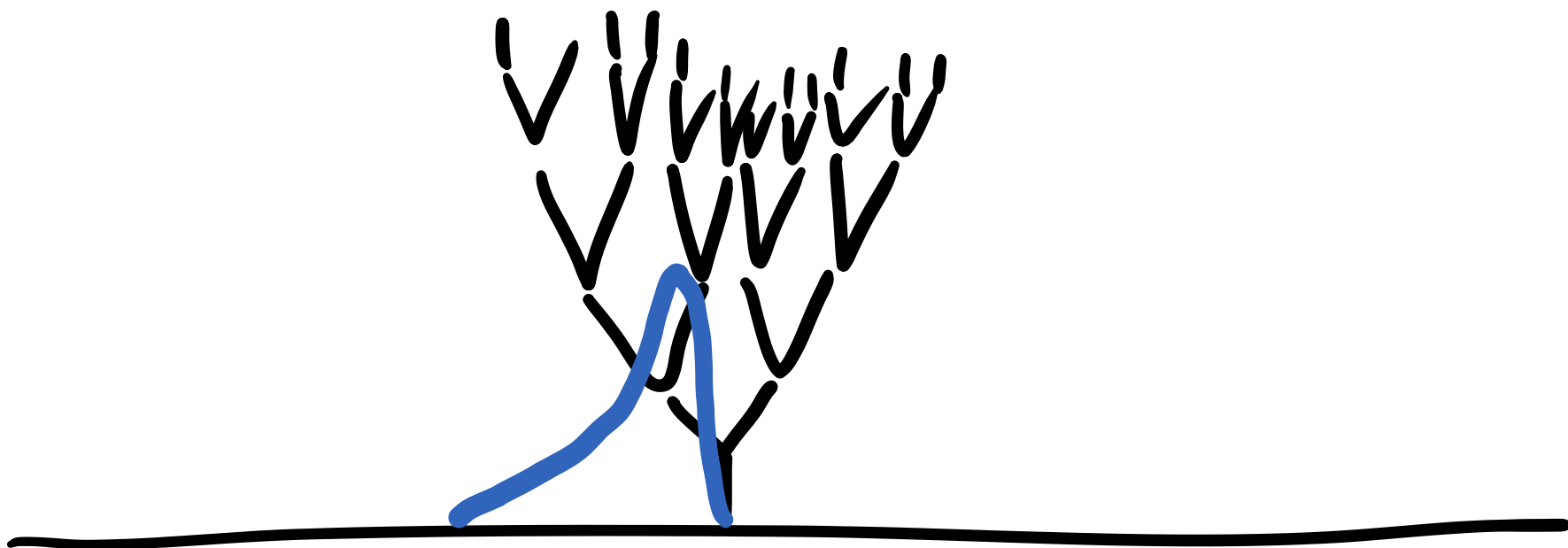


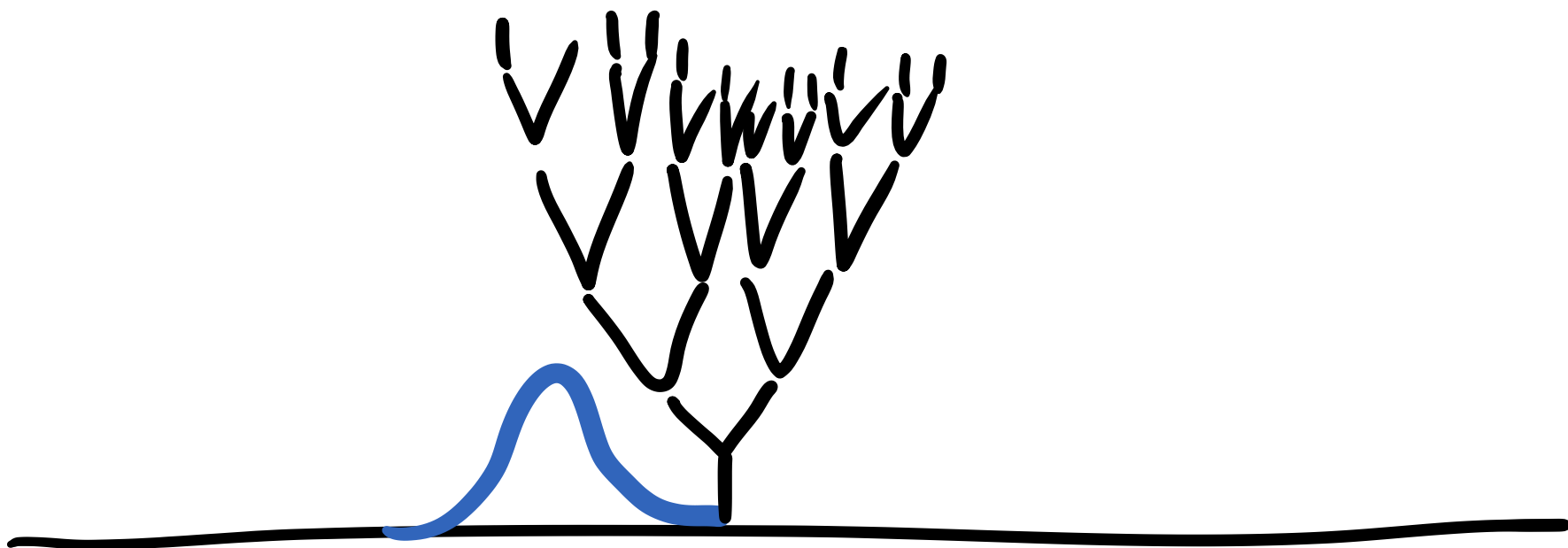


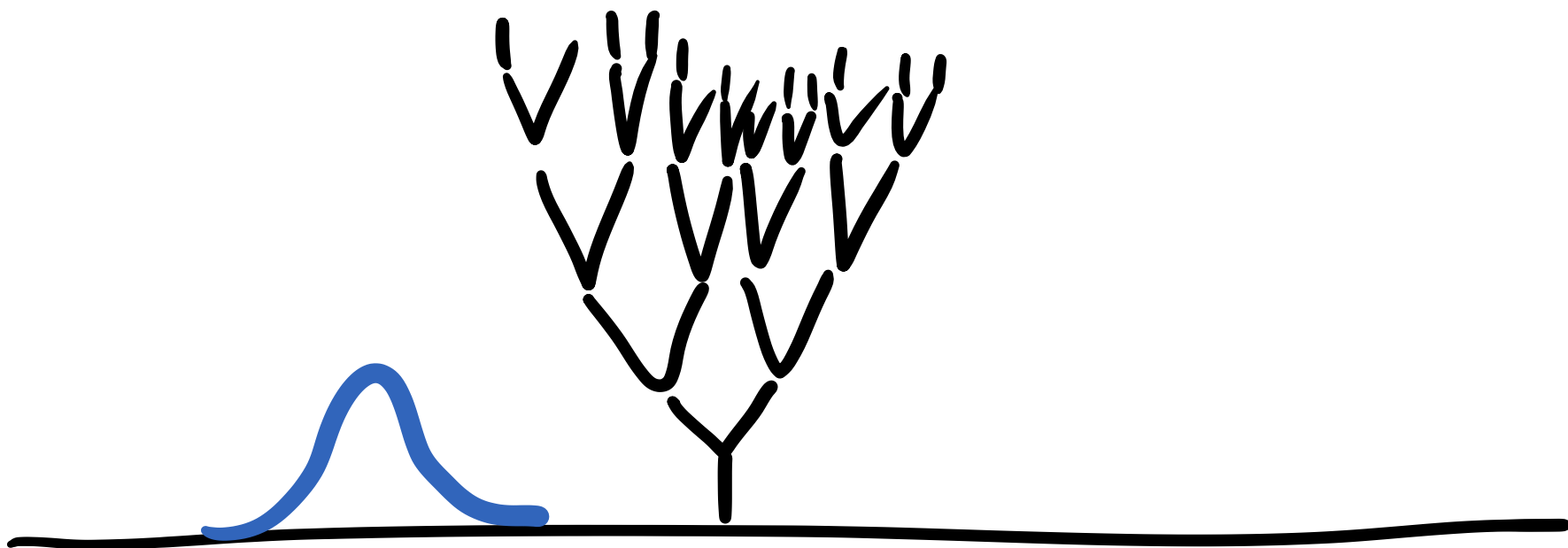




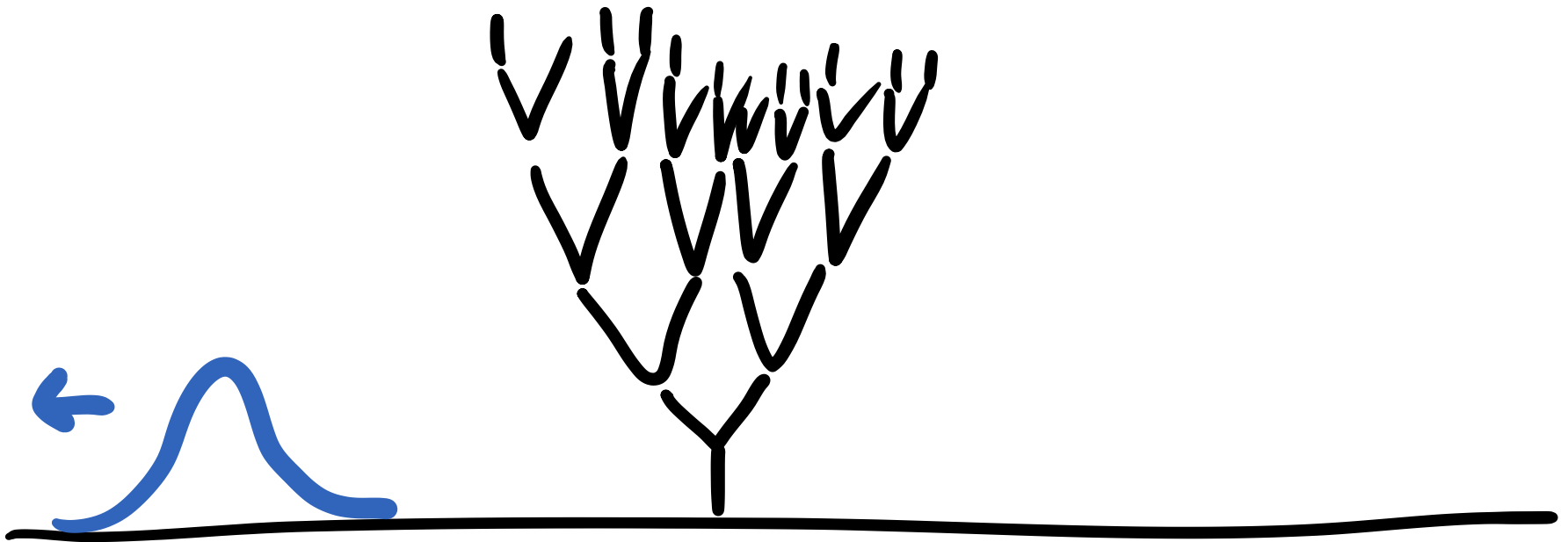


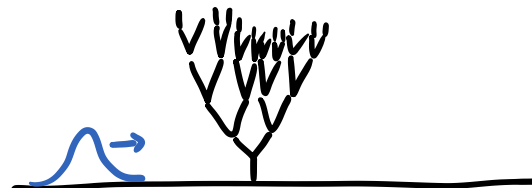
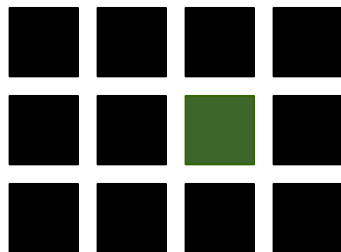
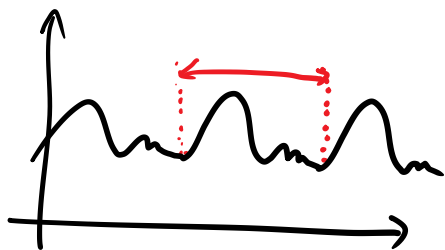






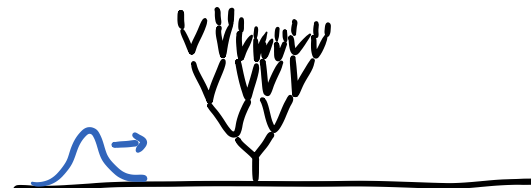
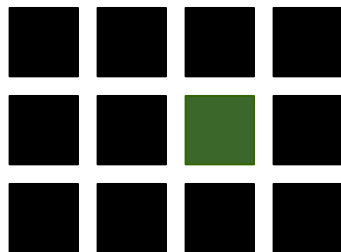
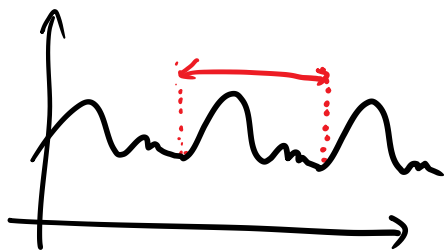
Rozptyl a herné stratégie (Farhi, Gutmann, Goldstone)





$$18388801 = ? \times ?$$

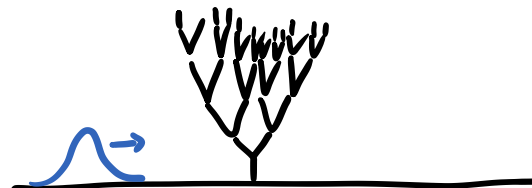
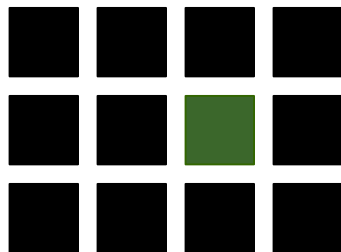
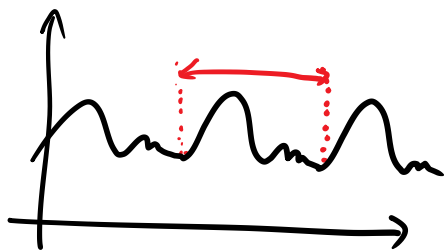
zaujímavá úloha



$$18388801 = ? \times ?$$



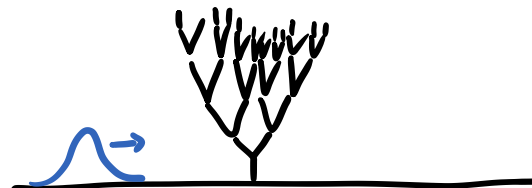
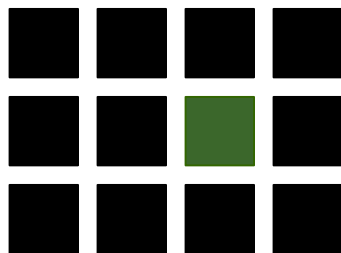
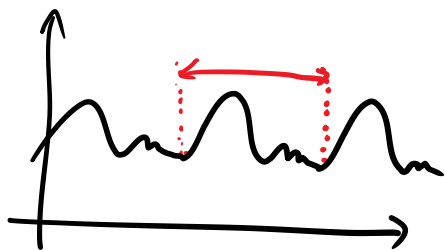
zaujímavá úloha
kvantový systém



$|1838880\rangle = ? \times ?$



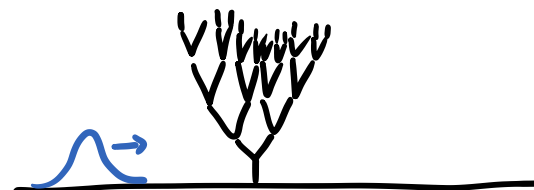
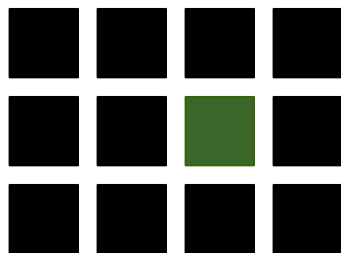
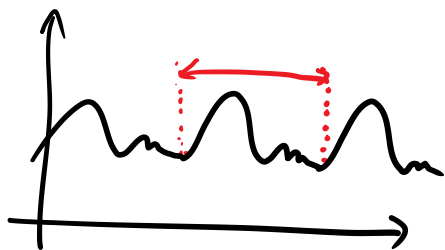
zaujímavá úloha
kvantový systém
inicializácia



$18388801 = ? \times ?$



zaujímavá úloha
kvantový systém
inicializácia
algoritmus



$$18388801 = ? \times ?$$

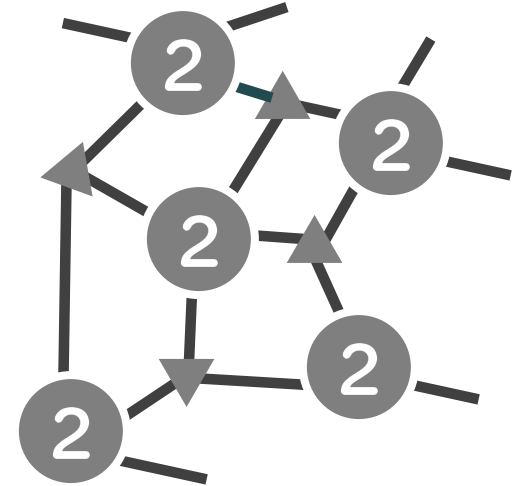


$$18388801 = 1999 \times 9199$$

zaujímavá úloha
 kvantový systém
 inicializácia
 algoritmus
 meranie

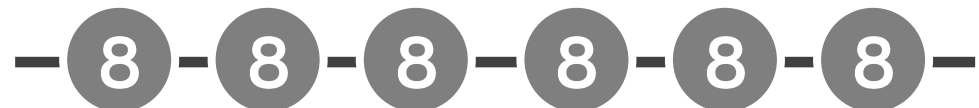
„jednoduché“ kvantové úlohy

ktoré budú ťažké
aj pre počítače,
ktoré ešte nemáme



[Gosset, N. '13]

[Hallgren, N., Narayanaswami '13]



čo nám príroda (ne)dovolí vypočítat'



Daniel Nagaj

| S A S



konferencia preveda
6/9/2016

Bratislava → MIT → UniWien → UC Berkeley → ...

theoretical physics *q.info* *condensed matter* *computational complexity*



physics teaching
& popularization

quantum
complexity
tensor networks
walks
annealing