Simulating nonlocal no-signaling correlations

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Outline

- Boxes: local, quantum, no-signaling
- Realizations: physical, logical (simulation)
- Technology: REST API
- Architecture
- Demonstration
- Outlook

Boxes

AKA box pairs:

- Alice:

  input $x \in \mathcal{X}$
  output $a \in \mathcal{A}$

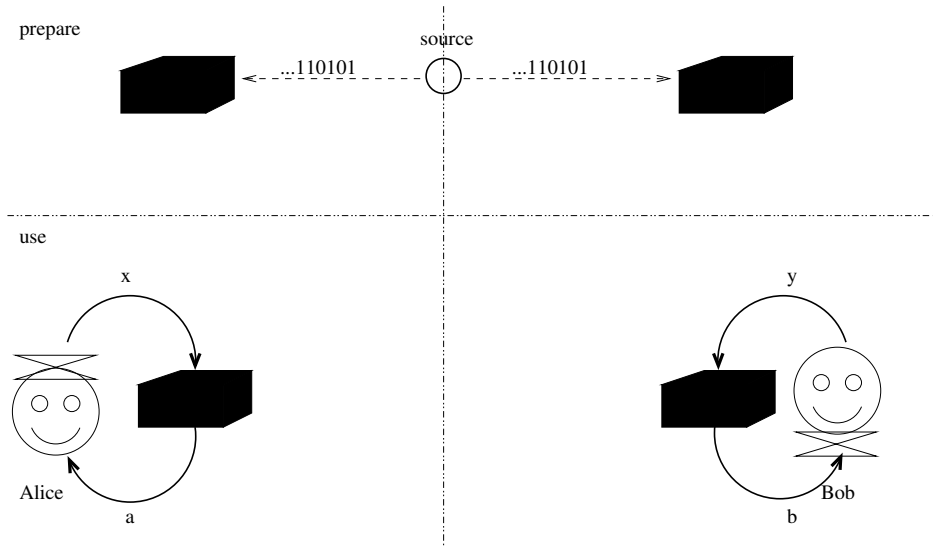
- Bob:

  input $y \in \mathcal{Y}$
  output $b \in \mathcal{B}$

Behavior:

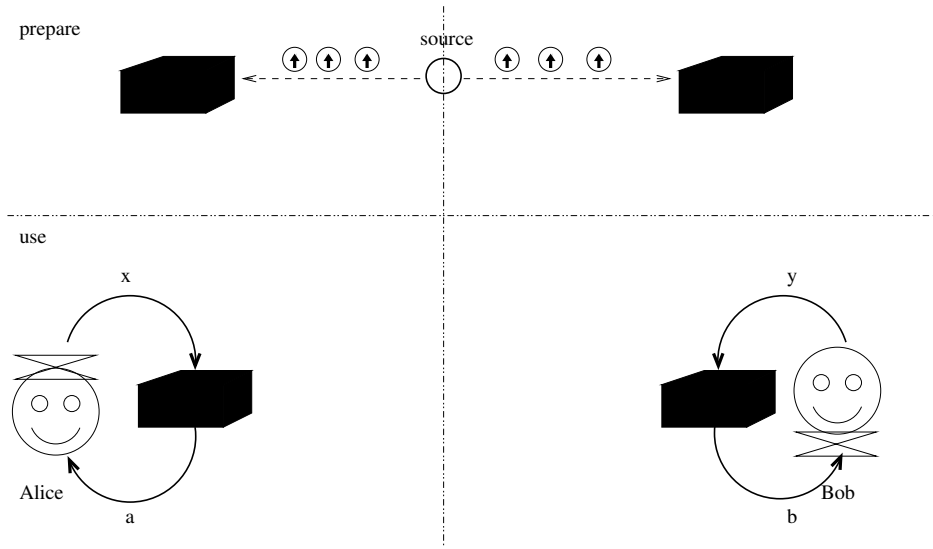
$$P(a, b|x, y)$$

Local boxes



$P(a, b|x, y)$ in the local polytope (Bell-inequalities).

Quantum boxes



$P(a, b|x, y)$ in a closed convex set.

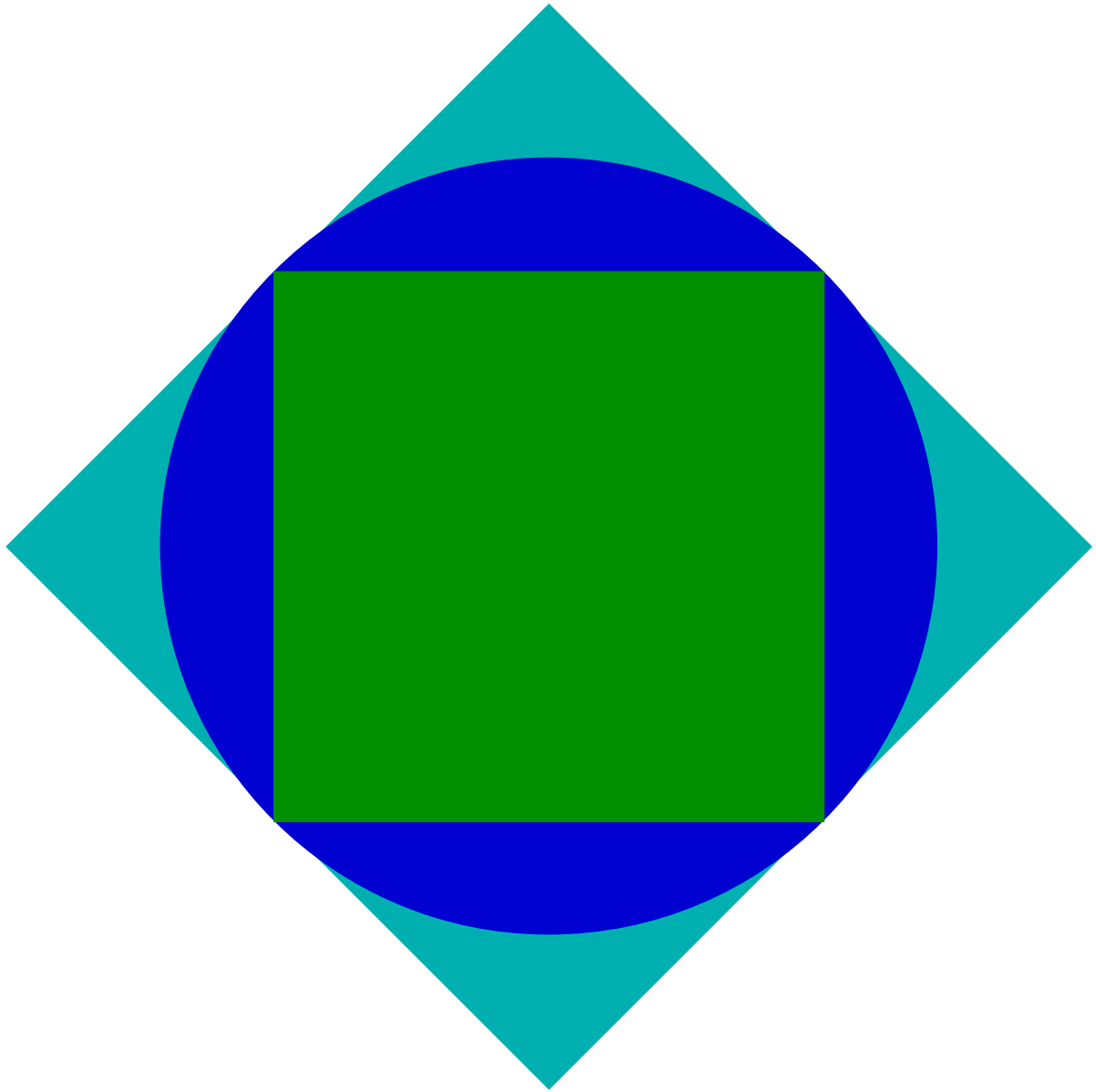
No-signaling boxes

$$\sum_b P(a,b|x,y) = P(a|x) \quad \forall y,$$

$$\sum_a P(a,b|x,y) = P(b|y) \quad \forall x.$$

- A polytope again.
- Superset of quantum and classical.
- Some cannot even be implemented with quantum.
- Interesting *per se*.

No-signaling boxes



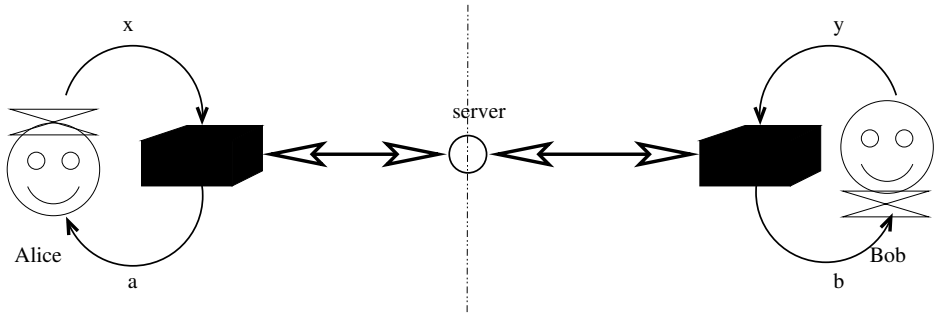
A prominent example: the PR box

Popescu-Rohrlich

$x\downarrow$	$y\rightarrow$	0		1	
	$a\downarrow$ $b\rightarrow$	0	1	0	1
0	0	$1/2$	0	$1/2$	0
	1	0	$1/2$	0	$1/2$
1	0	$1/2$	0	0	$1/2$
	1	0	$1/2$	$1/2$	0

- An extremal non-physical one towards the Clauser-Horne-Shimony-Holt inequality
- Game. . .

Simulated box

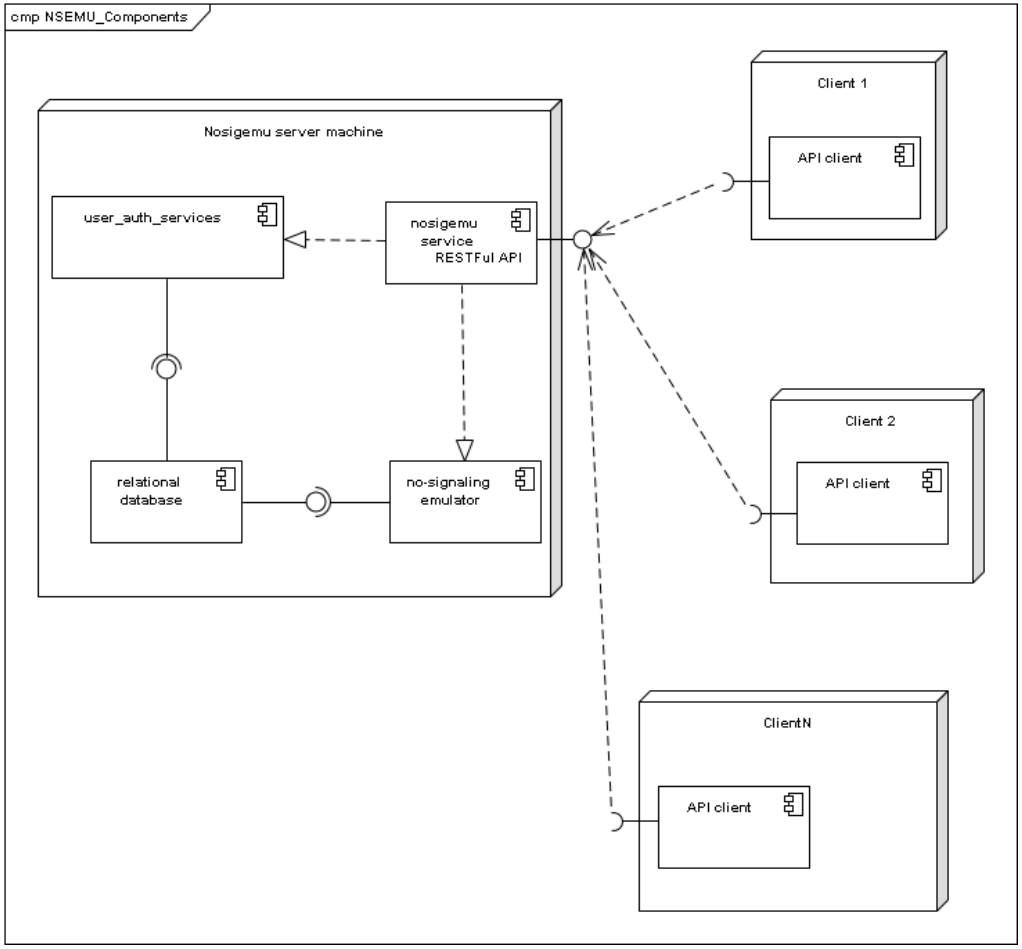


- Logical implementation.
- Trusted elements.
- Good for testing and development.

Technology: REST API

- REST $\sim$ representational state transfer
- Simple HTTP GET requests
- Essentially remote function calls on the server
- Industry standard
- Huge market (c.f. `programmableweb.com`)

System architecture



For generating the random events,
we use a "Quantis" USB Quantum Random Number generator.

`https://github.com/kmatyas-wig/quantis_rand`

Jump right in

- Play the CHSH game
- We use `curl` (Linux, MAC)
- In PowerShell, for instance do something like

```
$APIResponse = Invoke-WebRequest -Uri $URI -UseBasicParsing
$Data = ConvertFrom-Json $APIResponse.Content
Write-Host -Object $Data
```

- Python: c.f. e.g.

  `https://realpython.com/api-integration-in-python`

- Our developer libraries will soon be available along with the service.

```
box_alice.use(0, "20220101001")
```

Alice invites Bob

Suppose Alice wants to play a CHSH game with Bob.

```
curl --get 'https://nonlocalbox.wigner.hu/api/v1/invitePartner
?boxType=1&boxName=fun&inviteUserName=bob
&apiKey=$APIKEY'

{"boxID":4,"status":0}
```

The server responds with a JSON containing the ID of the newly created box (boxID: 4) and the status value of 0, which means that no error occurred during the execution of the API call. Alice can list all the boxes available for her:

```
curl --get 'https://nonlocalbox.wigner.hu/api/v1/listBoxes?
apiKey=$APIKEY'

{"boxes":[{"aliceUser":"1","bobUser":"2","boxTypeID":"1",
"created":"2022-06-13 10:41:13","id":"4","name":"fun"}],
"status":0}
```

Play the game

Suppose Alice sends x=0 as her input to box 4. She must create a transaction ID, which can be the current date and a 3-digit zero-padded number:

```
curl --get 'https://nonlocalbox.wigner.hu/api/v1/useBox?
boxID=4&transactionID=20220613001&x=0
&apiKey=$APIKEY'

{"a":1,"boxID":4,"status":0}
```

The box has emitted the reply a=1.
Bob sends $y = 0$ as his input with the same transaction ID.
Note that for $x = y = 0$ the results should be correlated, so Bob should get b=1:

```
curl --get 'https://nonlocalbox.wigner.hu/api/v1/useBox?
boxID=4&transactionID=20220613001&y=0
&apiKey=$APIKEY'

{"b":1,"boxID":4,"status":0}
```

Play the game 2

In the next transaction, Bob will be the first to send $y = 1$ as his input. Note that the transaction ID is incremented:

```
curl --get 'https://nonlocalbox.wigner.hu/api/v1/useBox?
boxID=4&transactionID=20220613002&y=1
&apiKey=$APIKEY'

{"b":0,"boxID":4,"status":0}
```

Assume Alice also sends $x = 1$ as her input. In that case, the results should be anticorrelated, that is, she should get $a = 1$ as a reply from the server:

```
curl --get 'https://nonlocalbox.wigner.hu/api/v1/useBox?
boxID=4&transactionID=20220613002&x=1
&apiKey=$APIKEY'

{"a":1,"boxID":4,"status":0}
```

Lessons to learn

- Transaction IDs
- No signaling: can appear in tricky ways
- Asynchronous $\rightarrow$ causal orders
  (this can be even useful, c.f.
  Bodor, Kálmán & Koniorczyk,
  `https://arxiv.org/abs/2201.09554` (2022))
- Applications: game theory, c.f.
  Koniorczyk, Bodor & Pintér,
  Phys. Rev. A **101**, 062115 (2020),
  cryptography?

The Wigner nonlocal box emulator ©

- Will be publicly announced soon (publication with details, website, blogs, etc.)
- Register via e-mail.
- Free for research use.
- Many box types available; any of them can be added upon request.

Go ahead and

- get your free account (email us),
- play the CHSH game with your friends,
- implement and test device-independent protocols,
- develop GUIs and applications