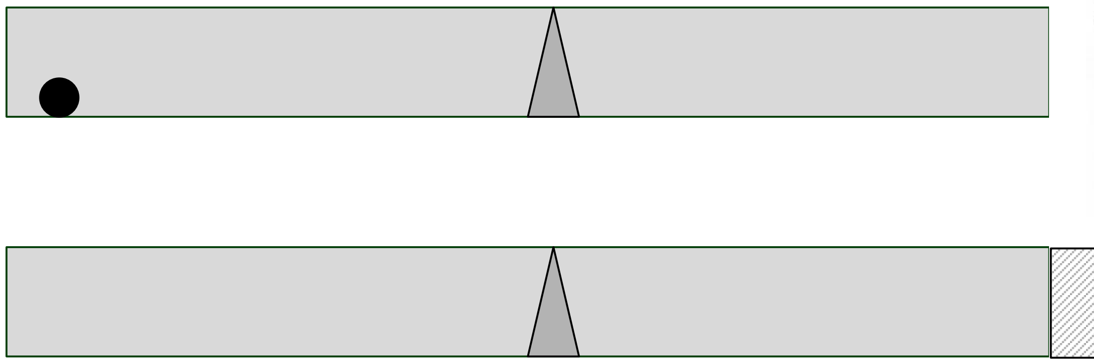
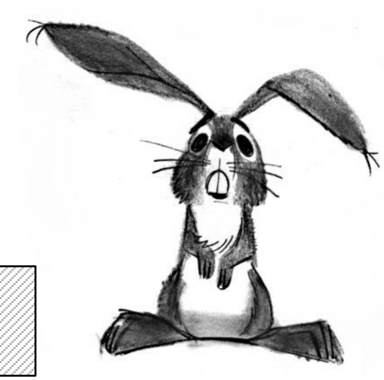
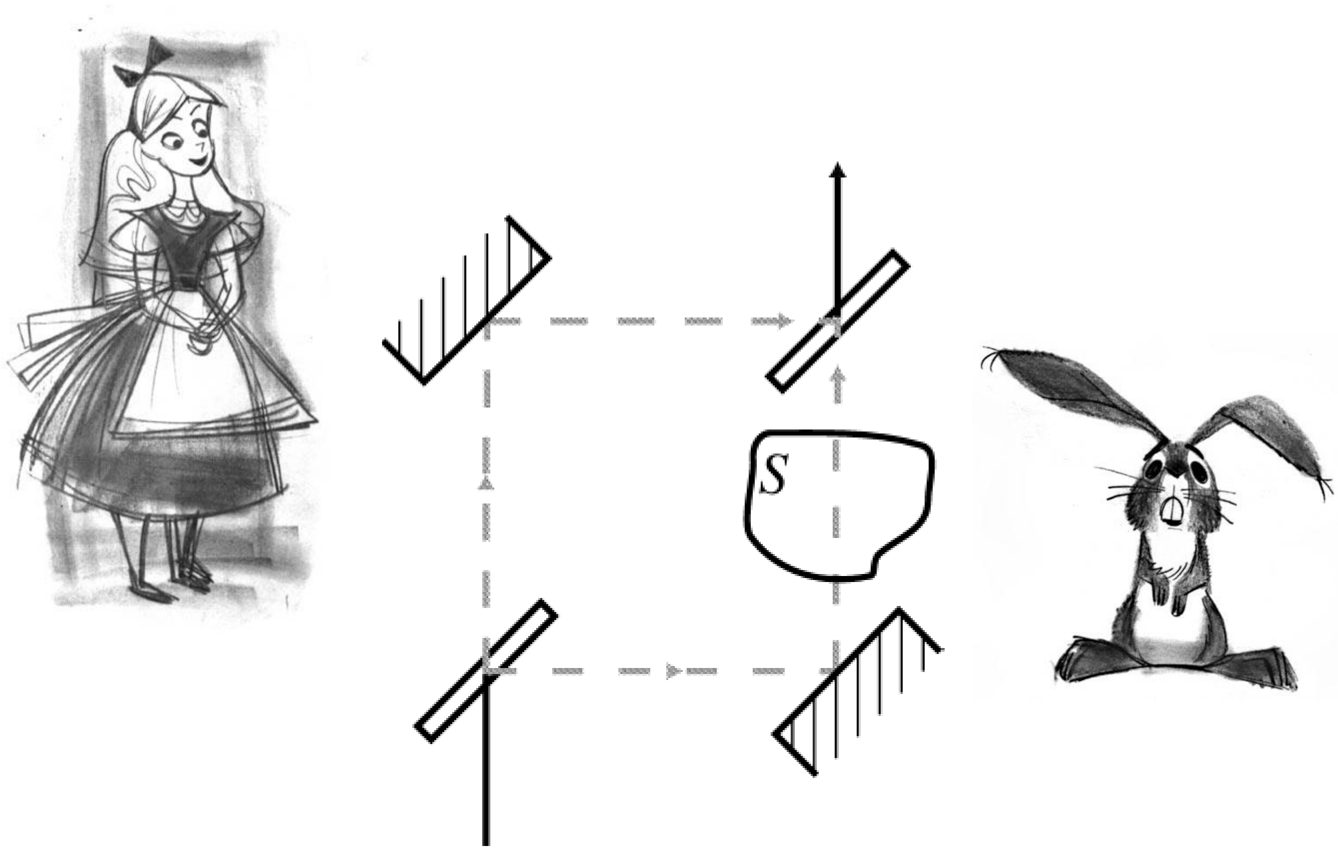
Locality and nonlocality

in “interaction-free” measurements

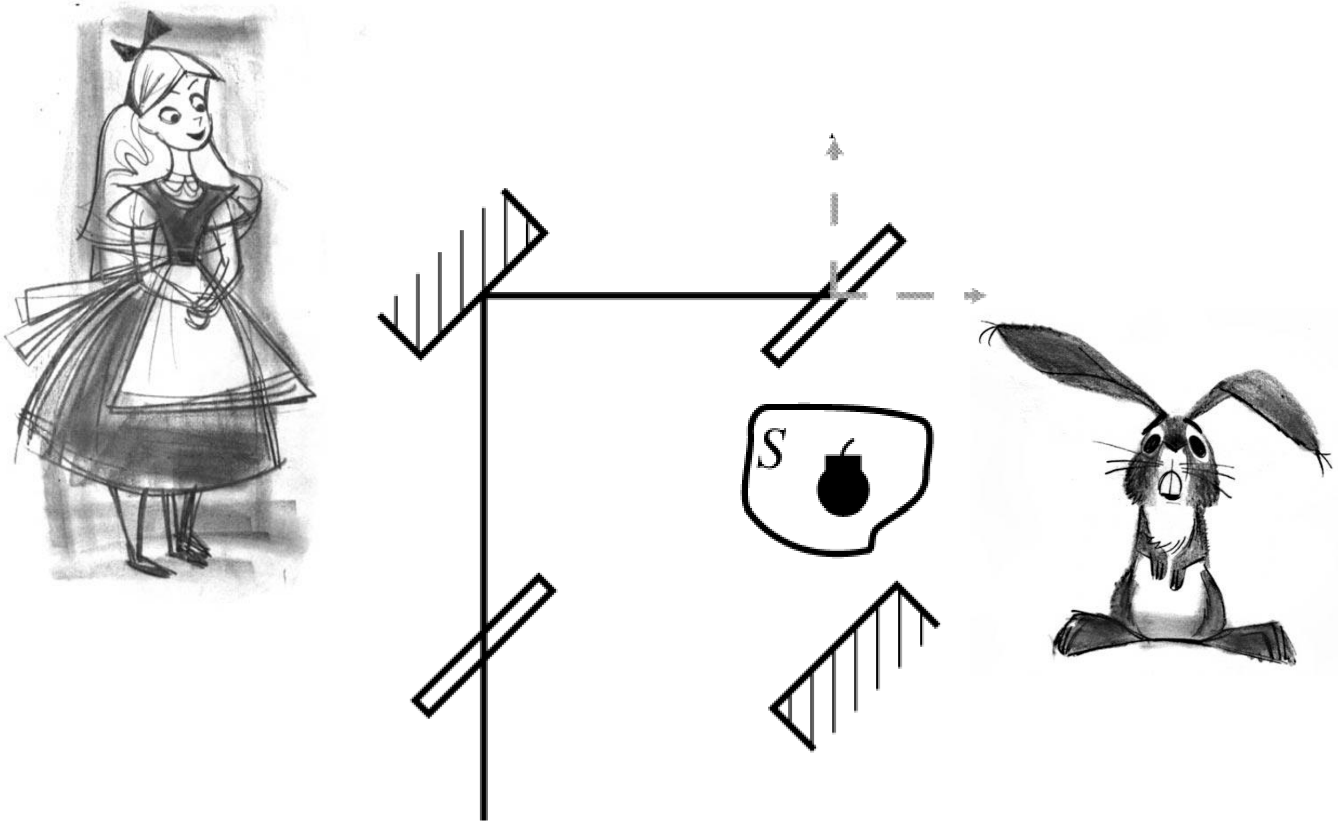




Y. Aharonov, T. Landsberger and D. Rohrlich (2017)



A. Elitzur and L. Vaidman, *Found. Phys.* **23**, 987 (1993)



A. Elitzur and L. Vaidman, *Found. Phys.* **23**, 987 (1993)

Outline

- What is “counterfactual communication”?
- A local “interaction-free measurement”
- “Counterfactual communication” revisited

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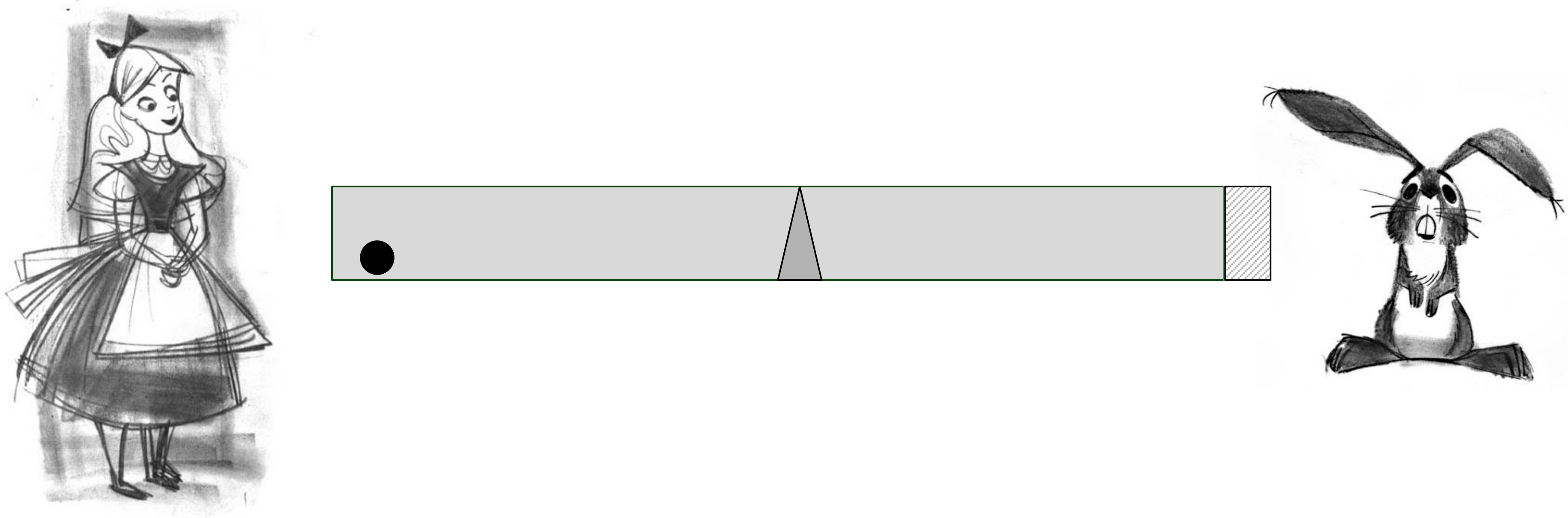
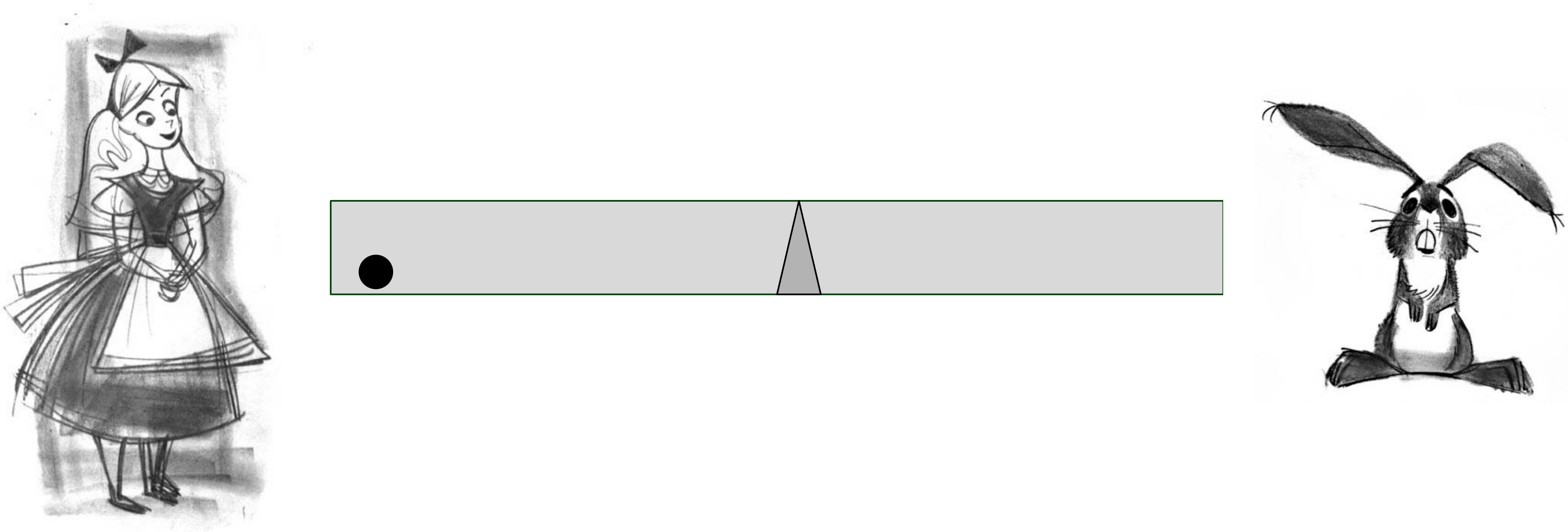
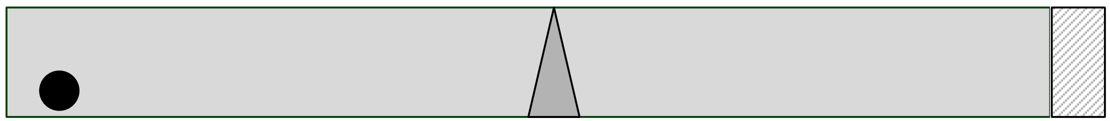
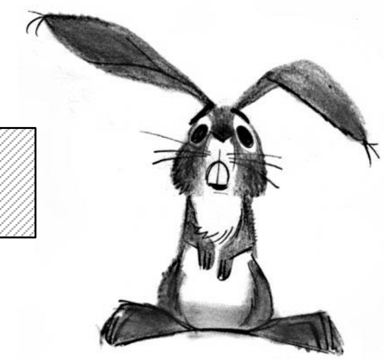
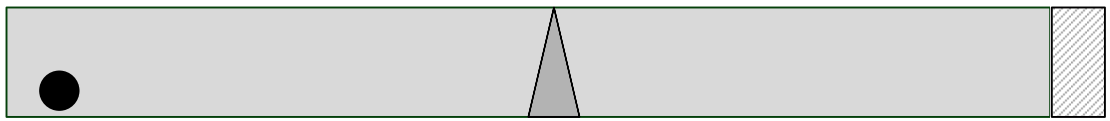


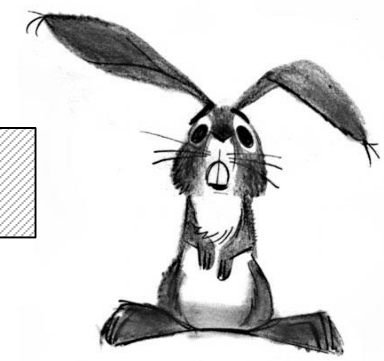






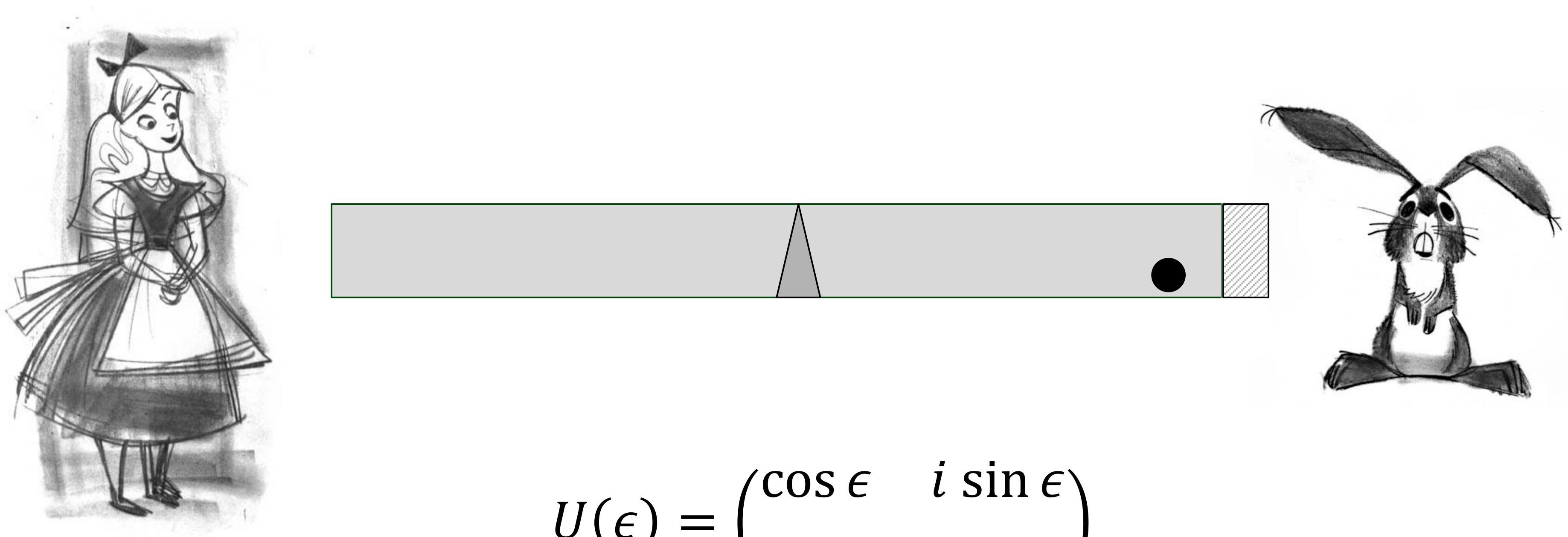
$$U(\epsilon) = \begin{pmatrix} \cos\epsilon & i\sin\epsilon \\ i\sin\epsilon & \cos\epsilon \end{pmatrix}$$





$$U(\epsilon) = \begin{pmatrix} \cos\epsilon & i\sin\epsilon \\ i\sin\epsilon & \cos\epsilon \end{pmatrix}$$

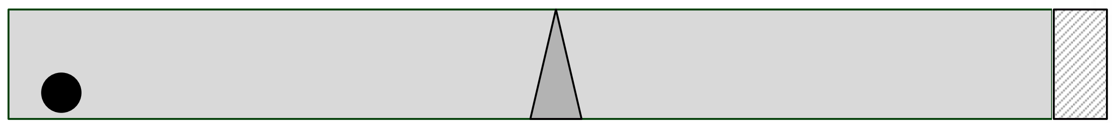
$$U^2(\epsilon) = \begin{pmatrix} \cos 2\epsilon & i\sin 2\epsilon \\ i\sin 2\epsilon & \cos 2\epsilon \end{pmatrix}$$

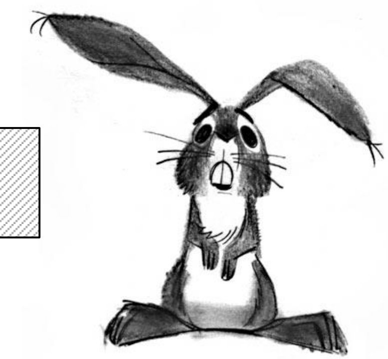


$$U(\epsilon) = \begin{pmatrix} \cos\epsilon & i\sin\epsilon \\ i\sin\epsilon & \cos\epsilon \end{pmatrix}$$

$$U^n(\epsilon) = \begin{pmatrix} \cos n\epsilon & i\sin n\epsilon \\ i\sin n\epsilon & \cos n\epsilon \end{pmatrix}$$

Let $n\epsilon = \pi/2$ at time T. Then the ball is in Bob's side.





$$U(\epsilon) = \begin{pmatrix} \cos\epsilon & i\sin\epsilon \\ i\sin\epsilon & \cos\epsilon \end{pmatrix}$$

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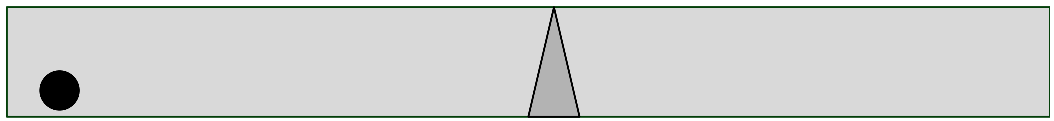
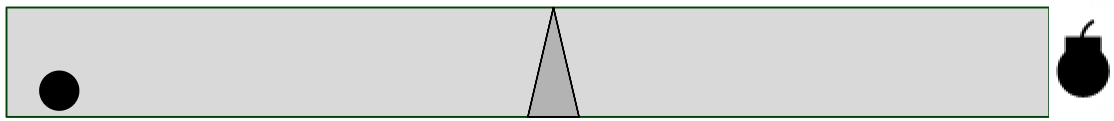
Let $n\epsilon = \pi/2$ at time T. Then the ball is in Bob's side.

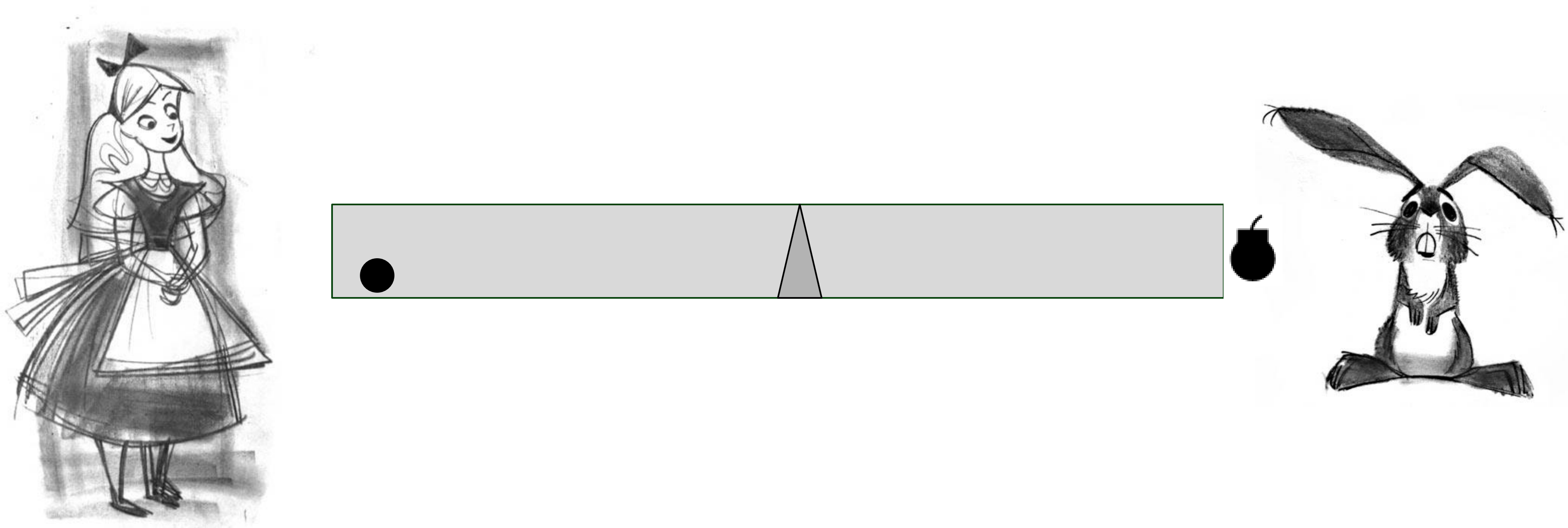
At time $2T$, the ball is back on Alice's side, multiplied by –1.



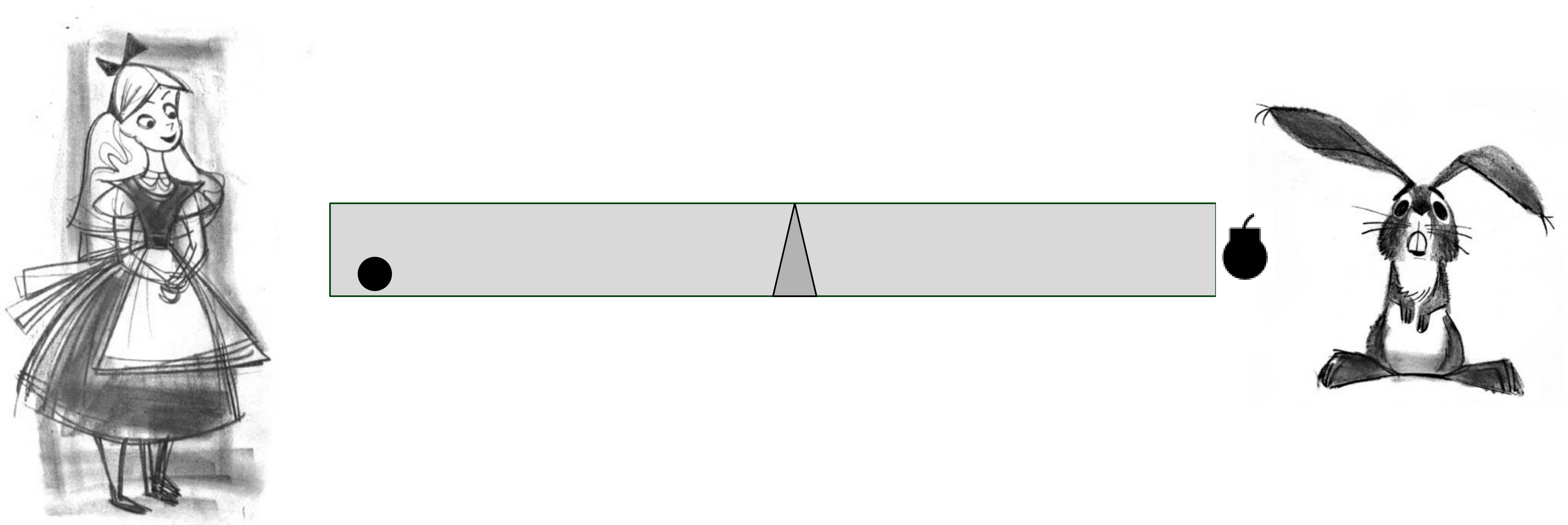
If Bob’s end is open (no mirror) –



If Bob’s end is open (no mirror) – or if Bob puts a bomb there instead of a mirror –



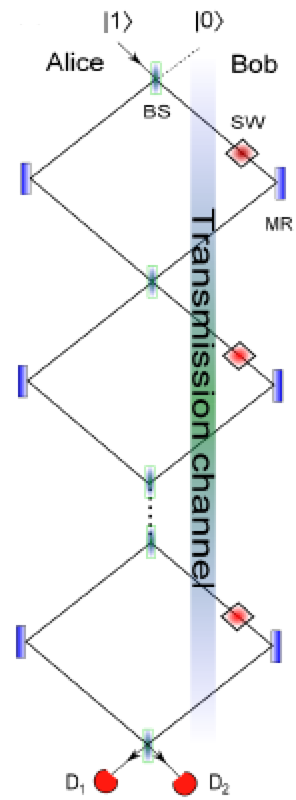
If Bob's end is open (no mirror) – or if Bob puts a bomb there instead of a mirror – then the chance of finding the ball on Bob's side at time T vanishes (amplitude ϵ and probability ϵ^2 per event, number of events proportional to $n = \pi/2\epsilon$).



If Bob’s end is open (no mirror) – or if Bob puts a bomb there instead of a mirror – then the chance of finding the ball on Bob’s side at time T vanishes (amplitude ϵ and probability ϵ^2 per event, number of events proportional to $n = \pi/2\epsilon$).

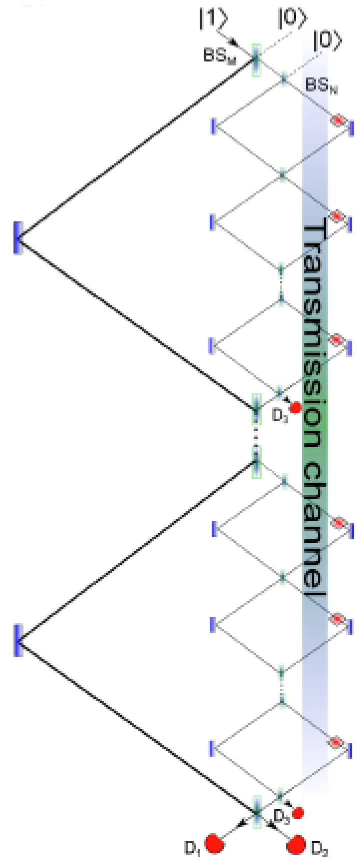
Thus the quantum Zeno effect makes the interaction-free measurement 100% reliable, and Bob can signal to Alice with no exchange of matter.

“Counterfactual communication”



H. Salih *et al*., *Phys. Rev Lett*. **110**, 170502 (2013)

“Counterfactual communication”



H. Salih *et al*., *Phys. Rev Lett*. **110**, 170502 (2013)

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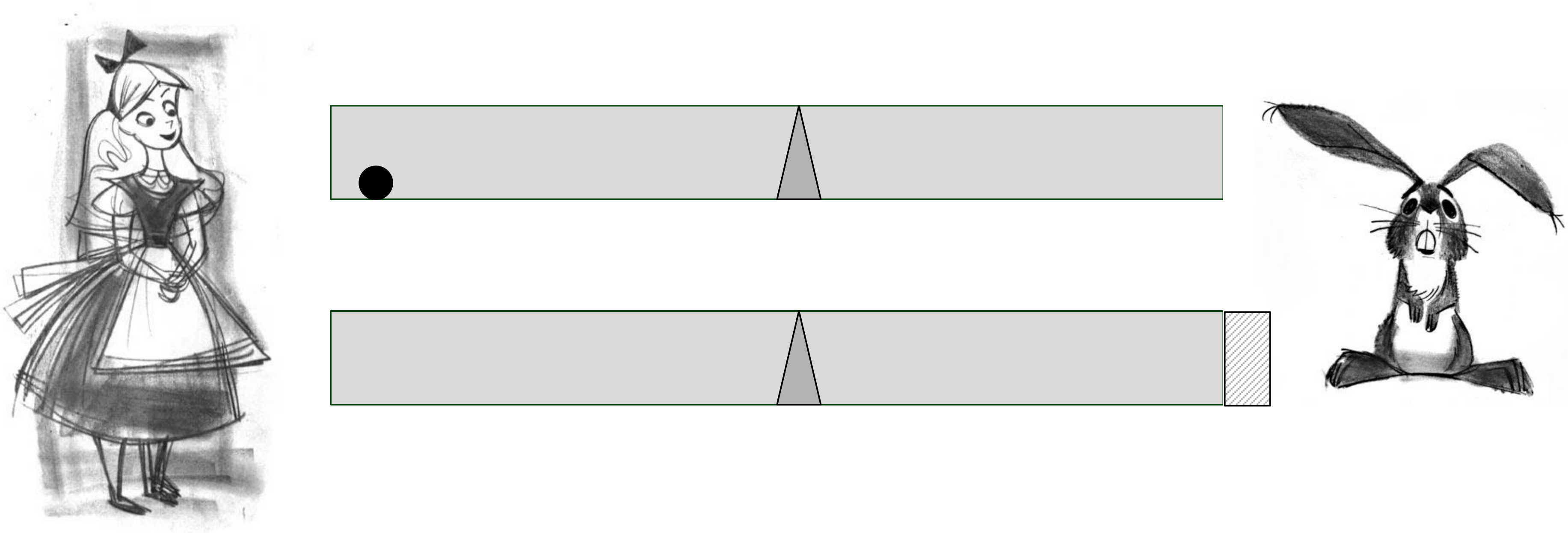
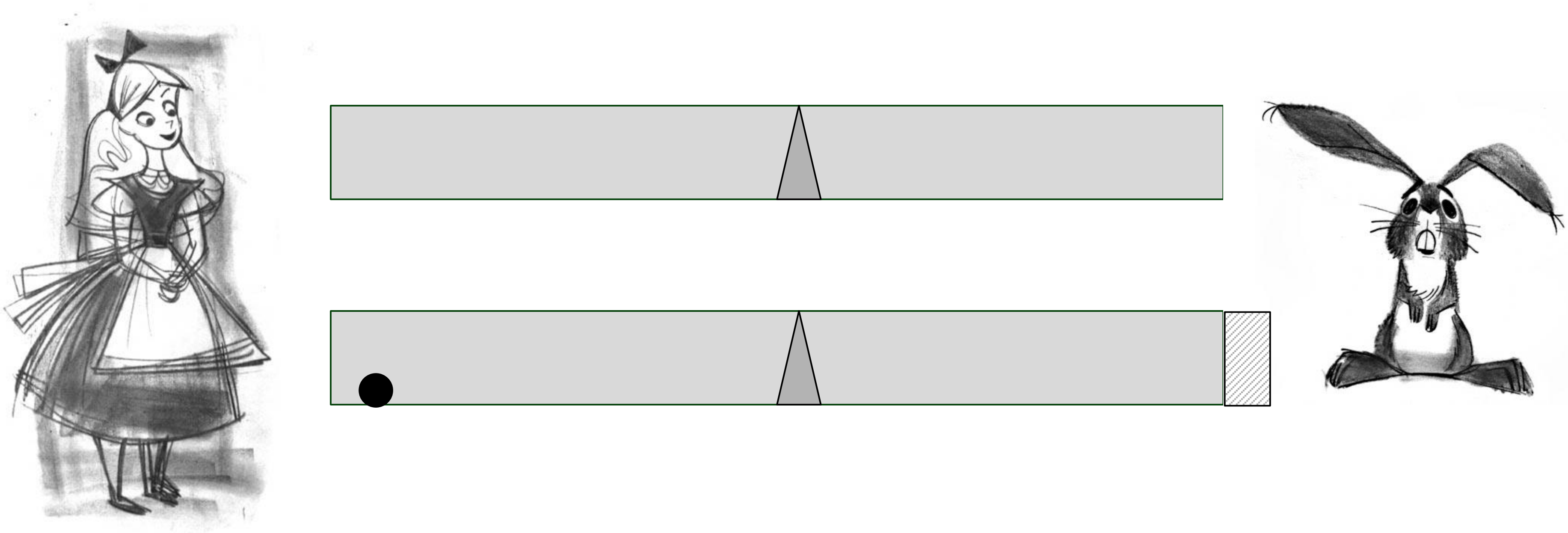
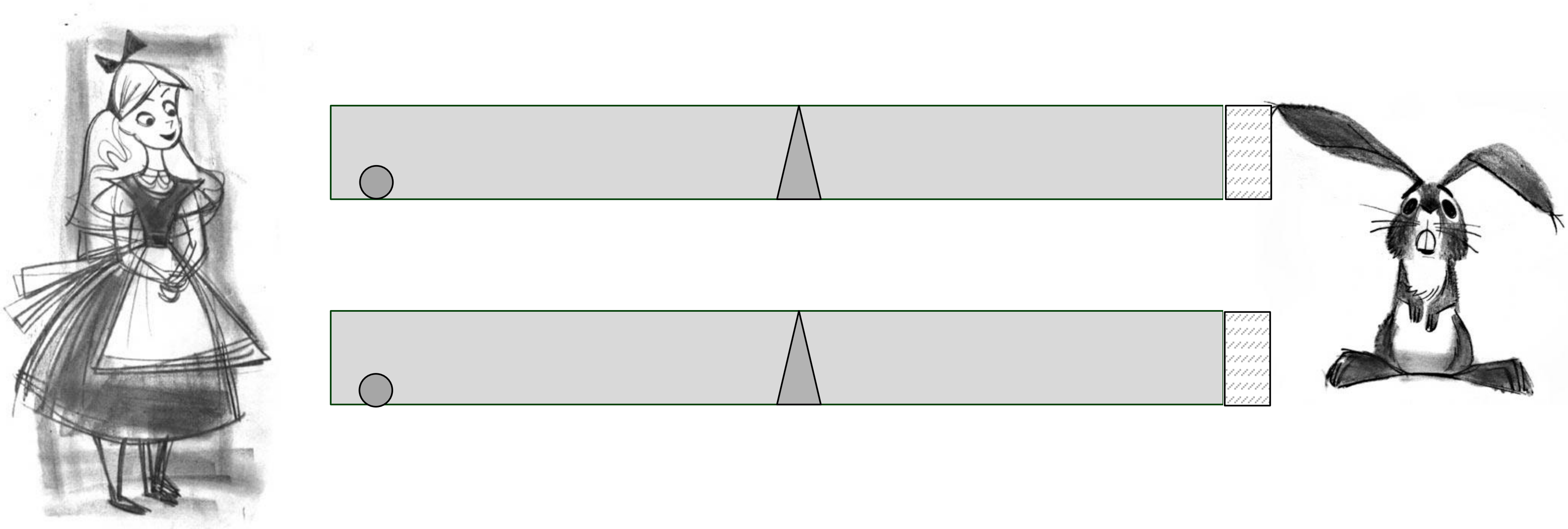


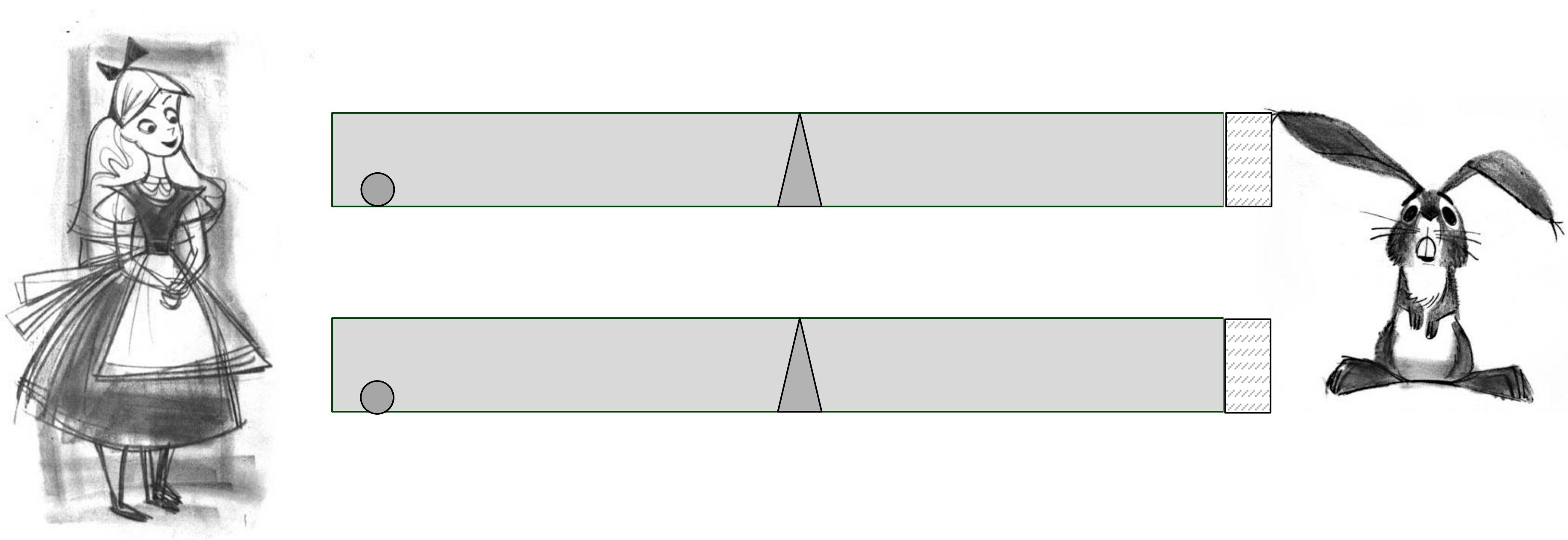


$$\Psi(0) = \frac{1}{2}(|\uparrow>_A + |\downarrow>_A)(|\uparrow>_B + |\downarrow>_B)$$



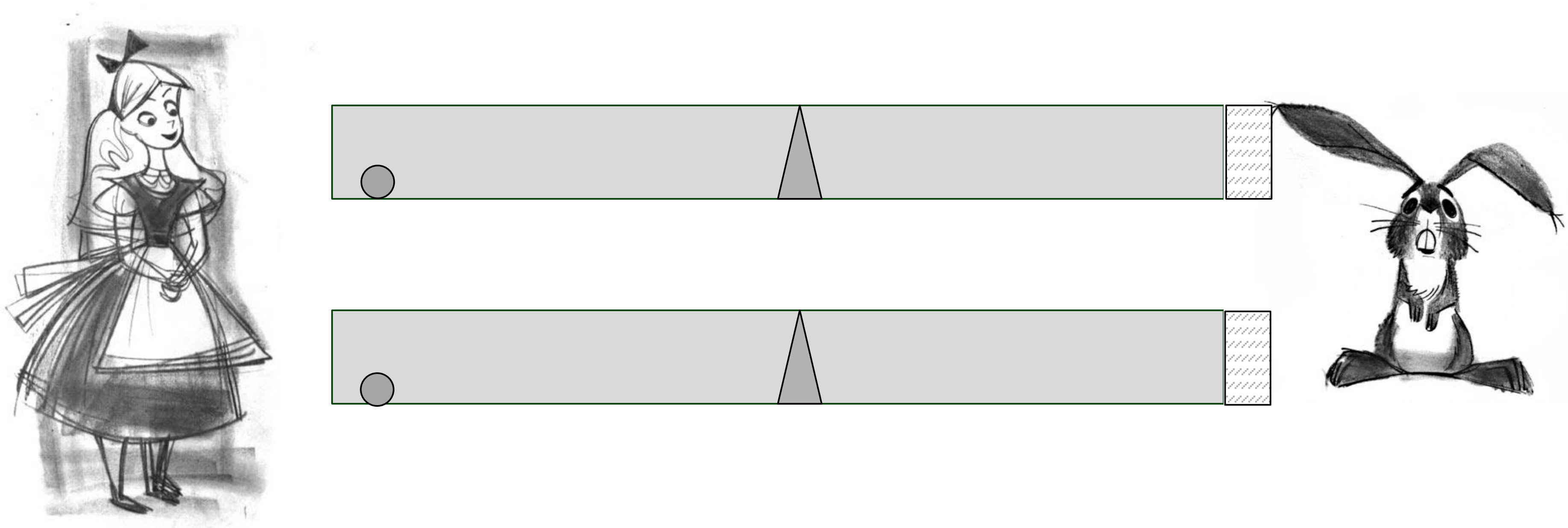
$\Psi(0)$ is an eigenstate at time $t = 0$ of the “modular angular momenta” L^A_{mod} and L^B_{mod}

$$\Psi(T) = \frac{1}{\sqrt{2}}[|\uparrow>_A|\downarrow>_B + |\downarrow>_A|\uparrow>_B]$$



$\Psi(0)$ is an eigenstate at time $t = 0$ of the "modular angular momenta" $L^A{}_{\text{mod}}$ and $L^B{}_{\text{mod}}$, and then at time $t = T$ Alice post-selects the ball on her side.

$$\Psi(T) = \frac{1}{\sqrt{2}}[|\uparrow>_B|\downarrow>_M + |\downarrow>_B|\uparrow>_M]$$



We find a *local* flow of a nonlocal physical quantity – modular angular momentum – on this pre- and post-selected ensemble.

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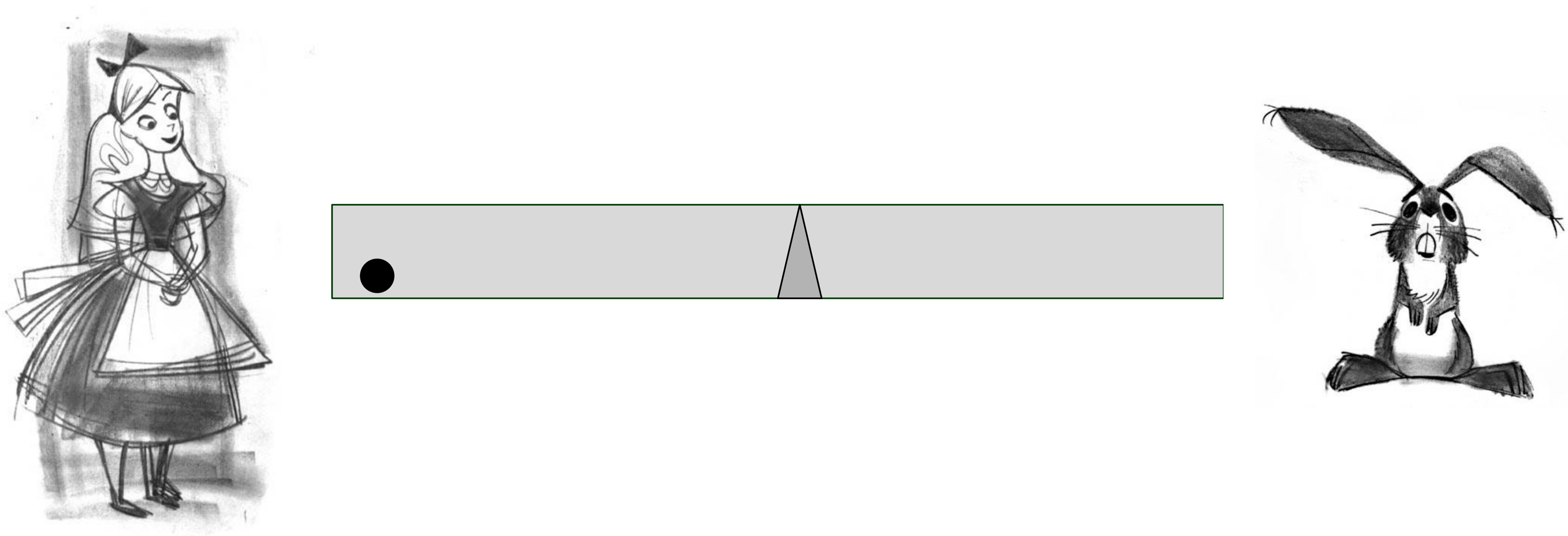
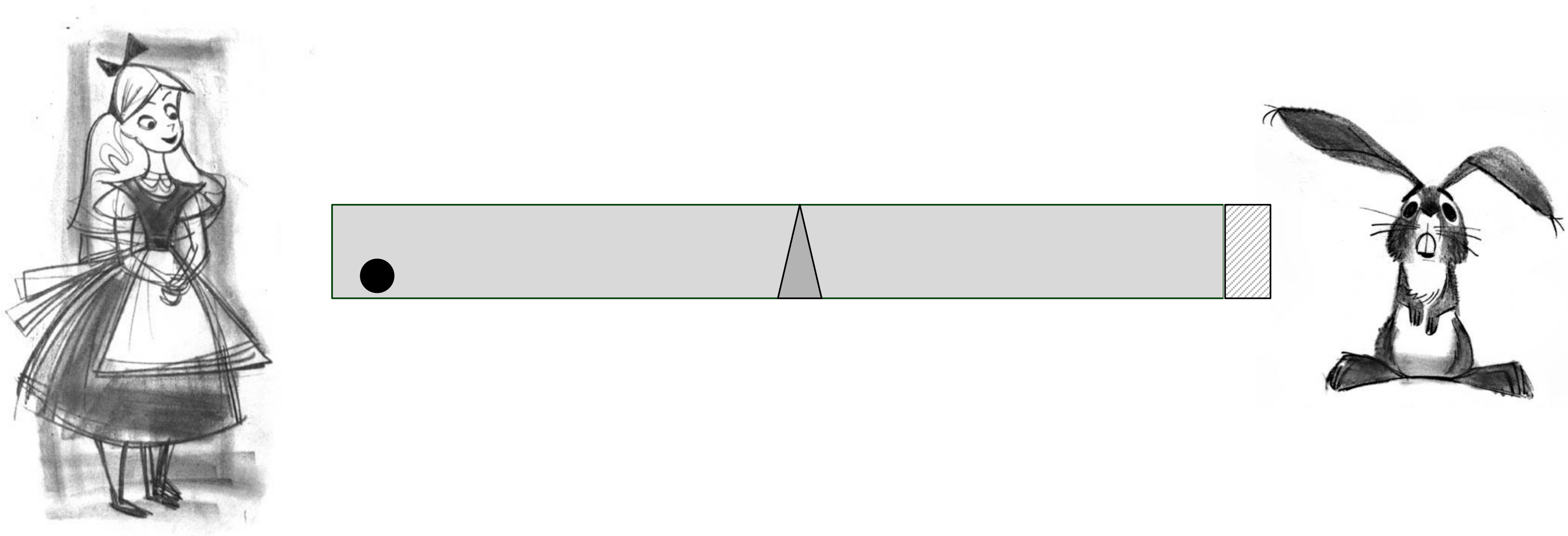
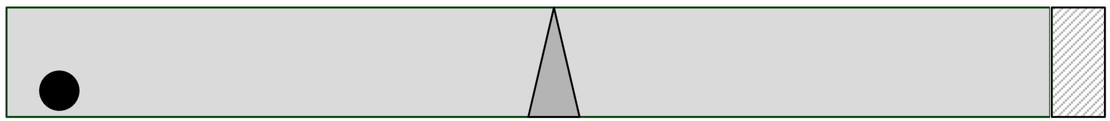
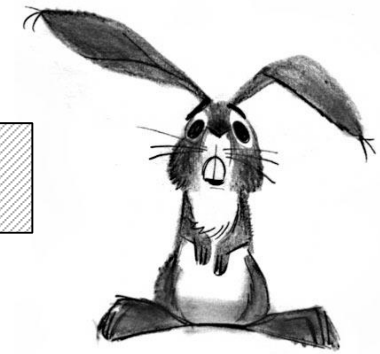


Alice finds the particle at her end after time *T*.

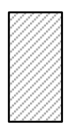
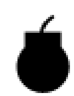


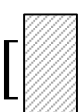
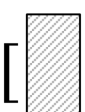
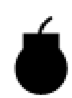
Alice *does not* find the particle at her end after time T.

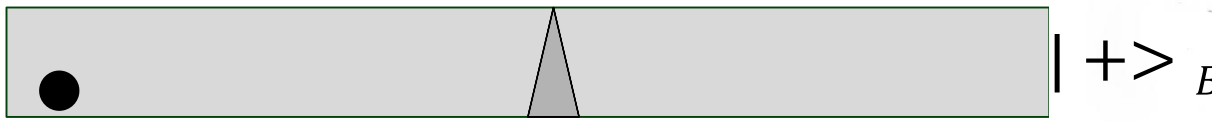


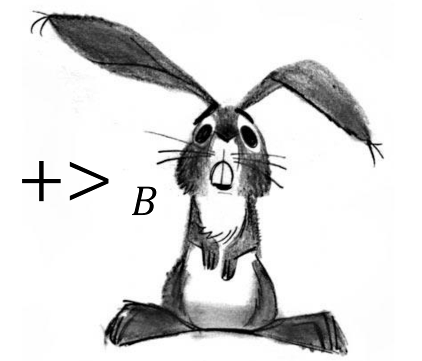


Alice *does not* find the particle at her end after time T.
Now let's define states

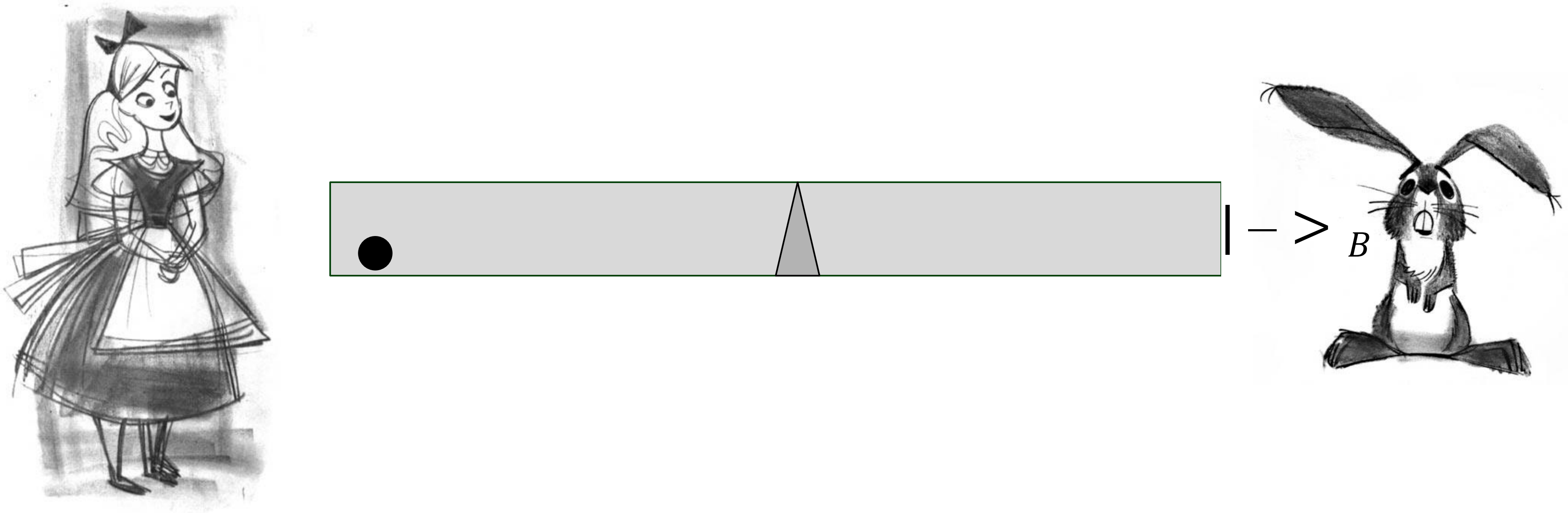
$|+>_B = \frac{1}{\sqrt{2}}[$  $+ \quad] = \frac{1}{\sqrt{2}}[$  $+$  $]$

$|->_B = \frac{1}{\sqrt{2}}[$  $- \quad] = \frac{1}{\sqrt{2}}[$  $-$  $]$





So now if Bob prepares his mirror in the state $| +>_B$, after time 2*T* it turns into $| - >_B$ and vice versa – not because of “counterfactual communication” but because the ball acquires a *local* phase along the way.



Conclusion: Bob may prepare the mirror *only* in the state $\frac{1}{\sqrt{2}}[|+>_B + |->_B]$ and thus *only* see “counterfactual communication”, but measurement in any other basis such as $|\pm>_B$ shows that the ball does reach Bob’s end.