When does a physical system compute?

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Lots of unconventional models of computation these days

Quantum computing
Quantum annealing
DNA Computing
Chemical computing

Leading people to describe many processes as computation

Do proteins do compaction computation while folding?
Do photons compute the shortest path through leaves?
Are our brains computers?
Is a rock a computer (simulating itself)?

If we define such things as computation then either:

We are wrong;
We just redefine 'computation' to mean 'physical process' and make the concept meaningless

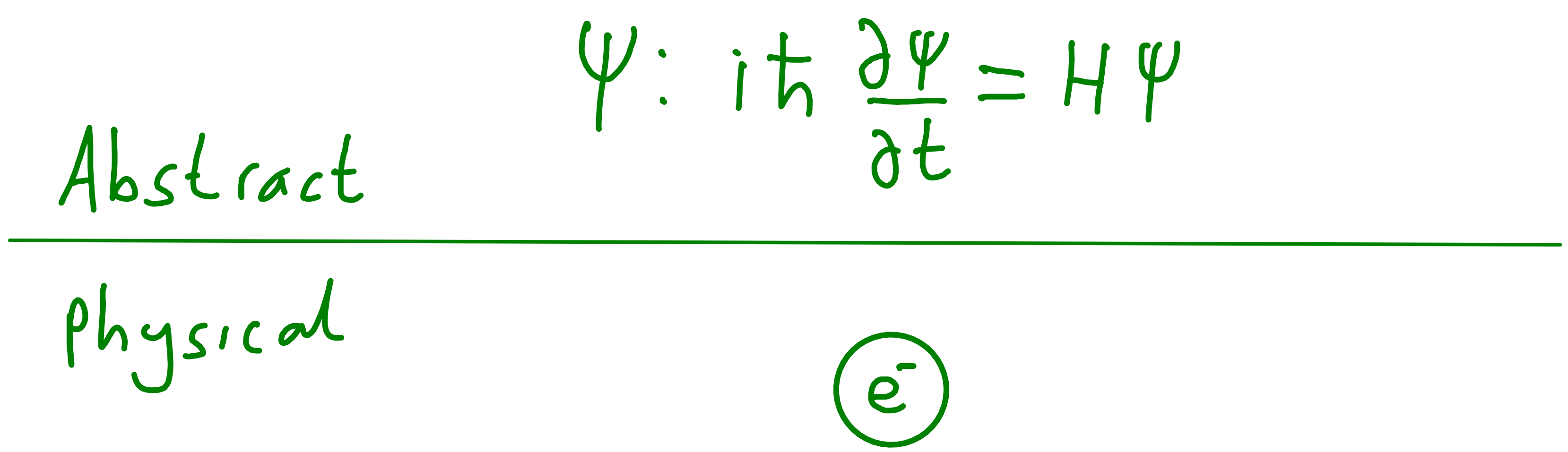
So how can we define computation in a meaningful way?

A `computation' is something ultimately described using the abstract languages of mathematics and logic of theoretical computer science.

A `computer' is a physical system.

The computer is taken to stand in a certain relation to the computation -- if we can formulate this relation, then we can answer our question of when a physical system is performing computation.

How does the abstract interact with the physical?



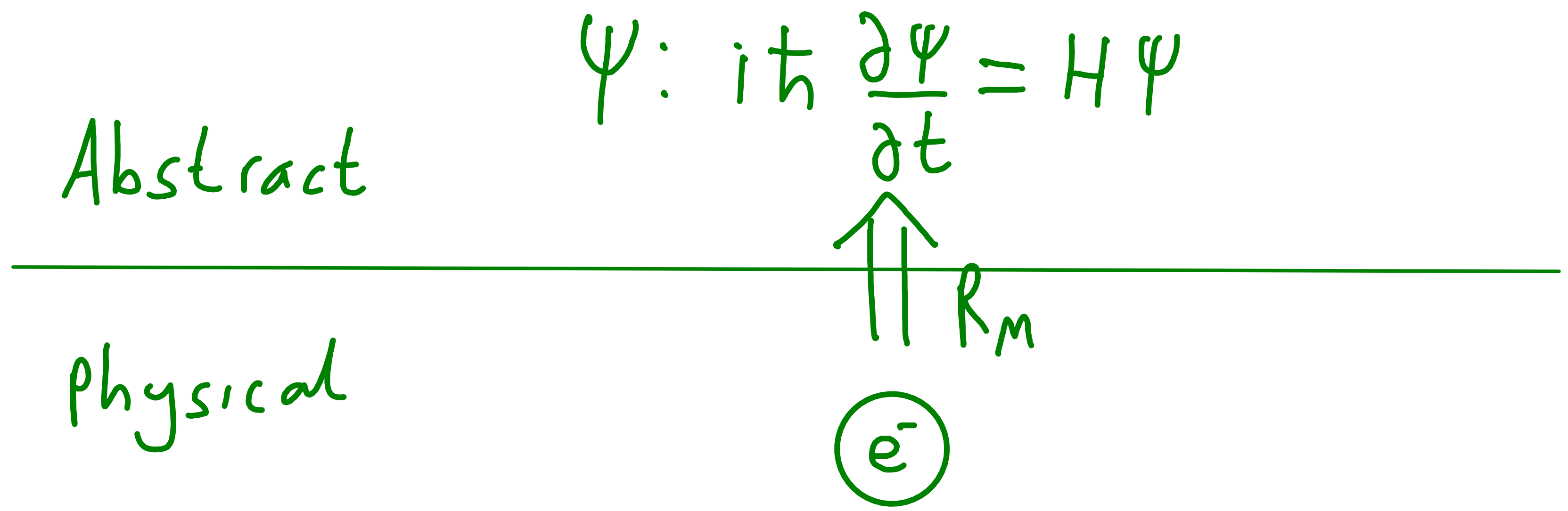
Physics is all about relating the abstract and the physical!

Physics operates by representing physical systems abstractly, using abstract theory to predict the outcome of physical evolution, and formulating physical experiments to test the outcome of theoretical predictions. Physics works by constant and two-way interaction between abstract and physical.

This is done with the representation relation.

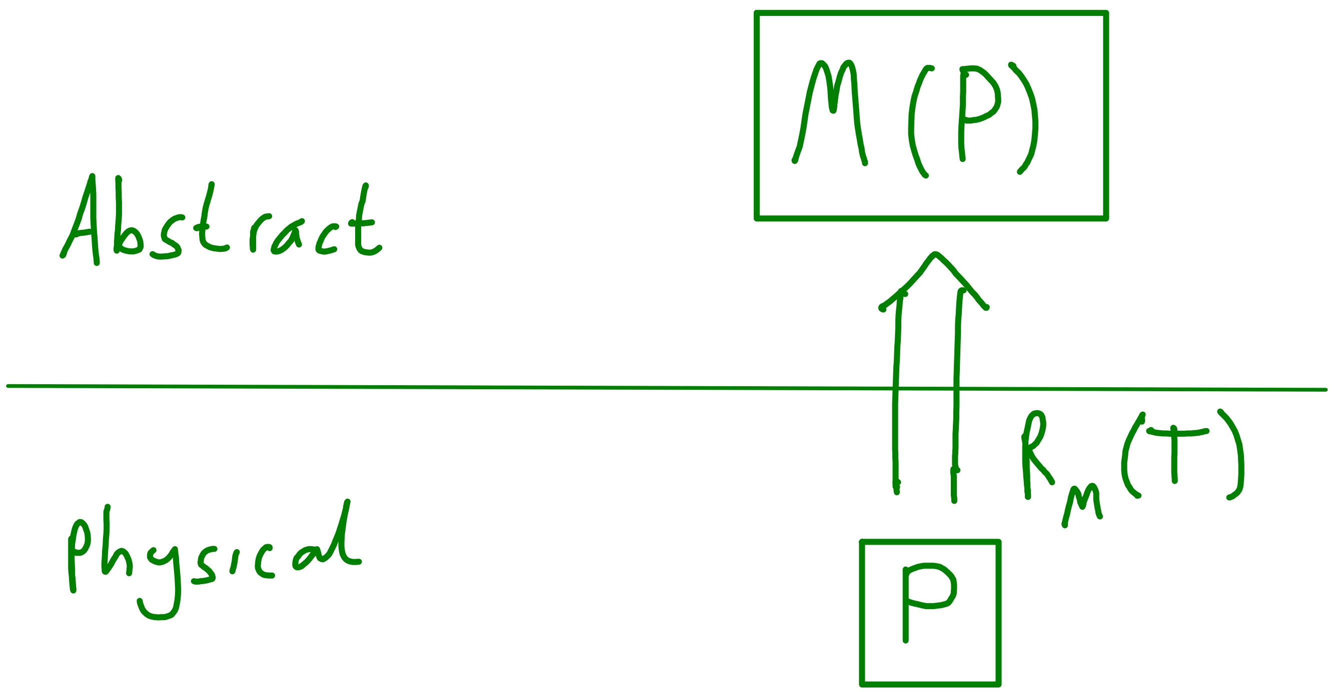
Philosophers are still trying to work out exactly what this is and how it works.

To physicists, though, it's just how you do physics: model something physical (spin 1/2) with something abstract (qubit)



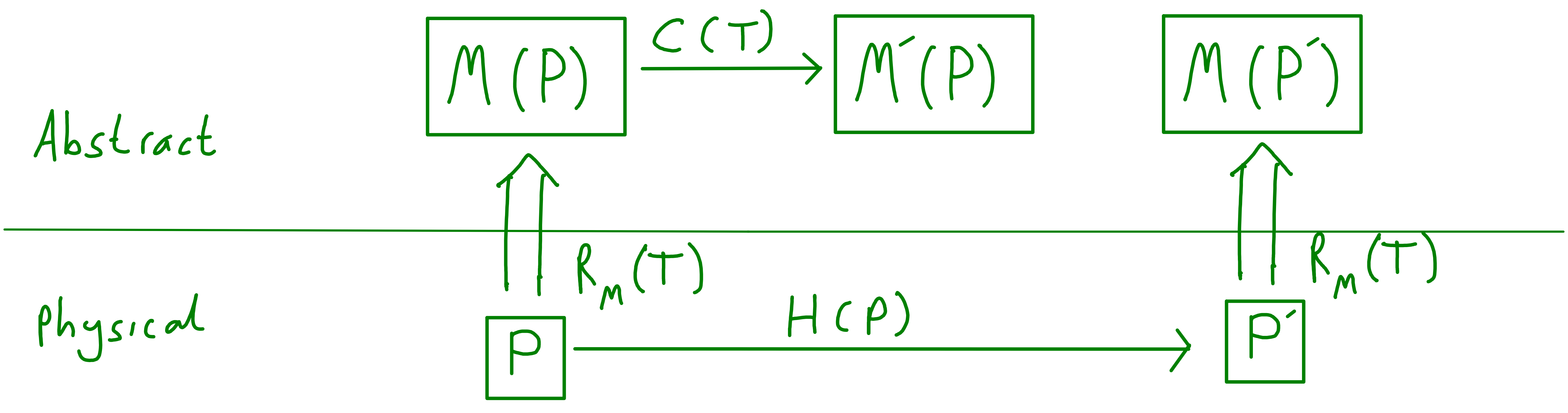
Relation is asymmetric: Not all models have corresponding physical systems

A "computer" is a physical system for which we have adequate abstract models, which we then exploit



Physical system P is represented by model M(P) through a relation that depends on the theory, T, used

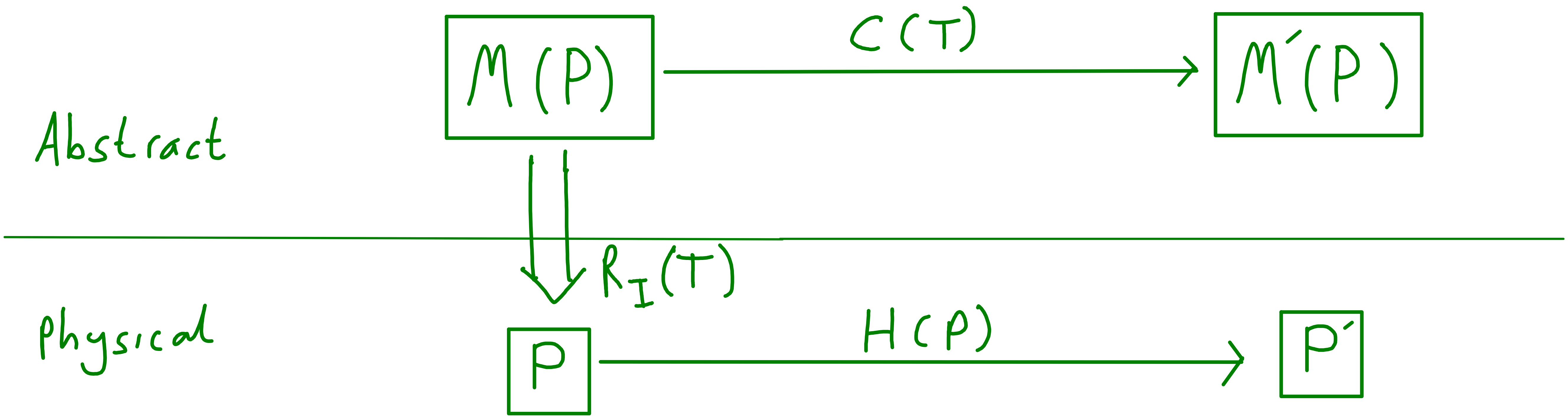
Then M(P) evolves due to abstract dynamics, and P due to physical dynamics



Experiments check if M'(P) = M(P'), and so if T is a good theory

When we have such a theory, we may find that fun things should happen in certain regimes that have never been probed experimentally.

We would then also like to find an 'instantiation relation', which allows us to prepare the P corresponding to some M(P)



Then, a "computer" is a physical system for which we have both $R_M(T)$ and $R_I(T)$, and we are sufficient confident that

$$M'(P) = M(P')$$

Even for cases we haven't tested explicitly

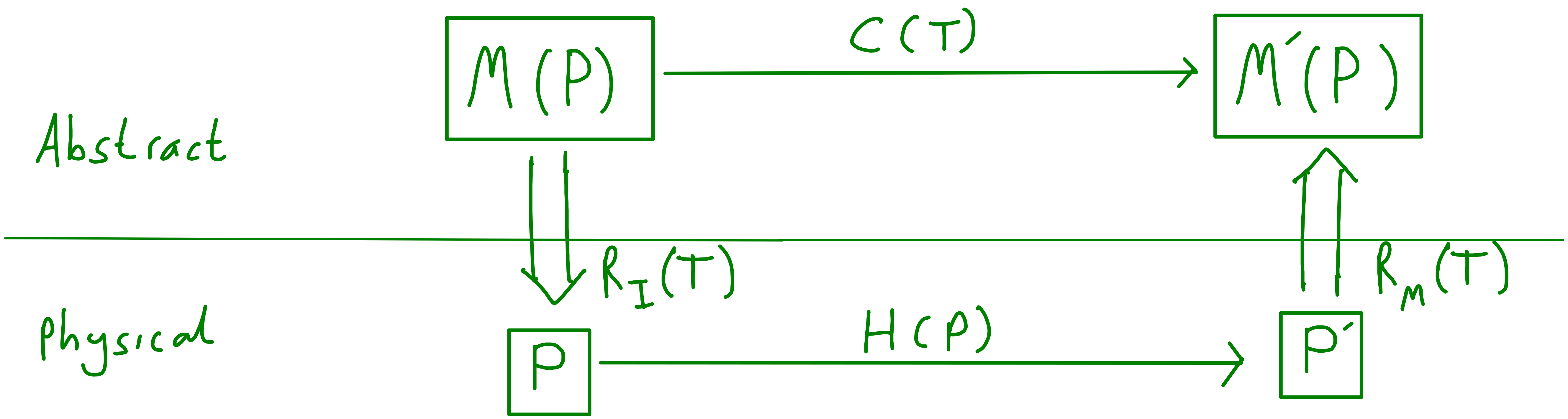
But computing starts with an abstract state M(P), and wants to determine the outcome M'(P) of an abstract evolution C(T). So we need to

1) Find P for M(P) (encoding)

2) Find H(P) for C(T)

3) Allow P to evolve according to H(P)

4) Determine M(P') (decoding)

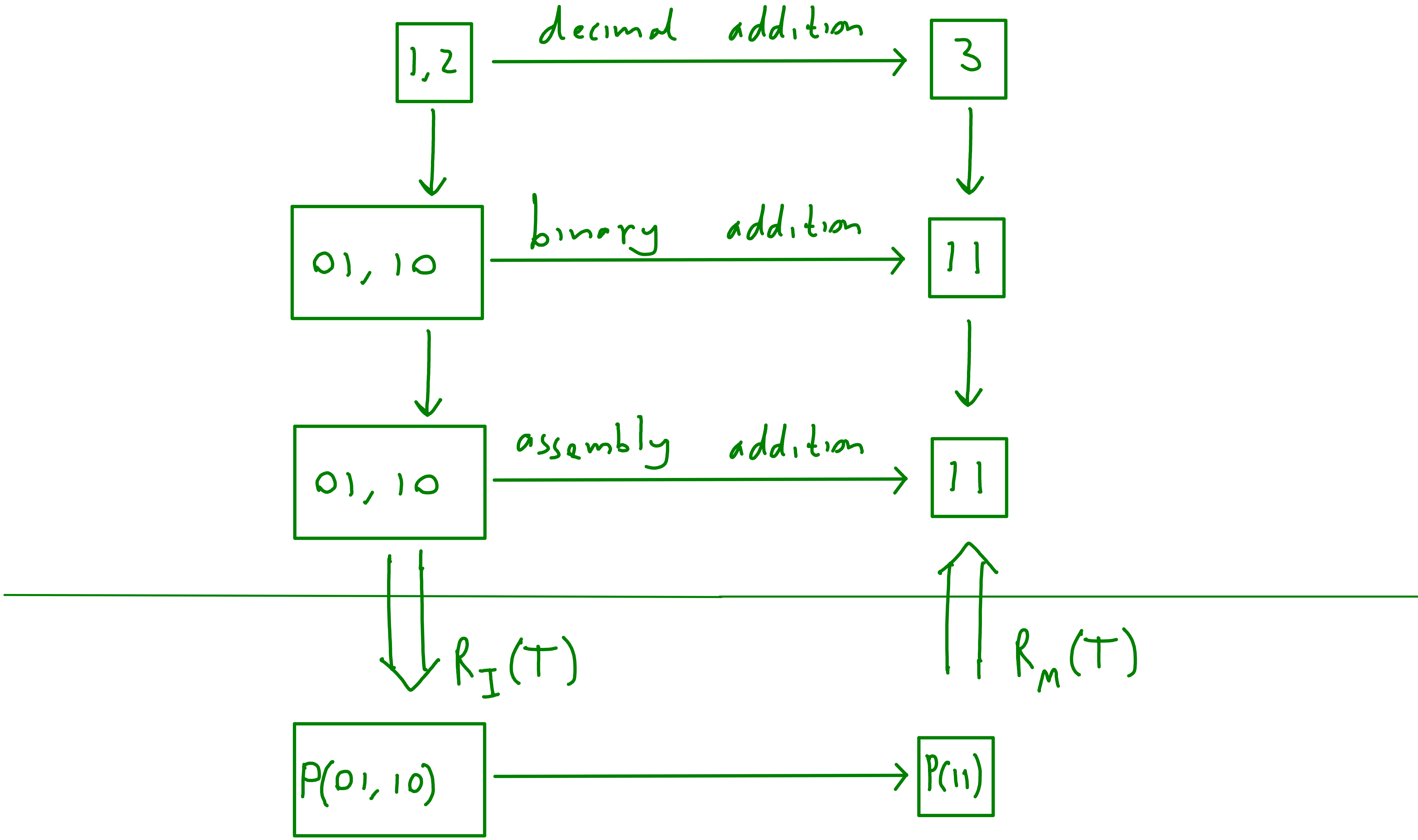


Since we trust that M(P')=M'(P), the physical system obtained our abstract solution for us. It acted as a computer.

Almost the exact opposite of experimentation.

In practice C(T) and H(P) are split up into smaller steps, through refinement and compilation

This gives extra stuff on the abstract side



Computational entities

A computer is distinguished from other physical systems by the encoding and decoding steps

This prevents us from describing the universe or a rock as a computer (just a potential computer)

But then we require an agent (the 'computational entity') doing the encoding and decoding. Does this make computation subjective?

They argue 'no' because

- The existence of the computational entity is objective
- The fact that they are encoding and decoding is objective
- They needn't be human (could be AI)
- We don't need to use ill defined notions such as conciousness

The authors then use an examples to confuse the reader

If a human writes and runs a program, then that is computation because they have sufficient intellect to intend the representations they make with their encoding

But if a cat walks across a keyboard to the same effect then it is not a computation

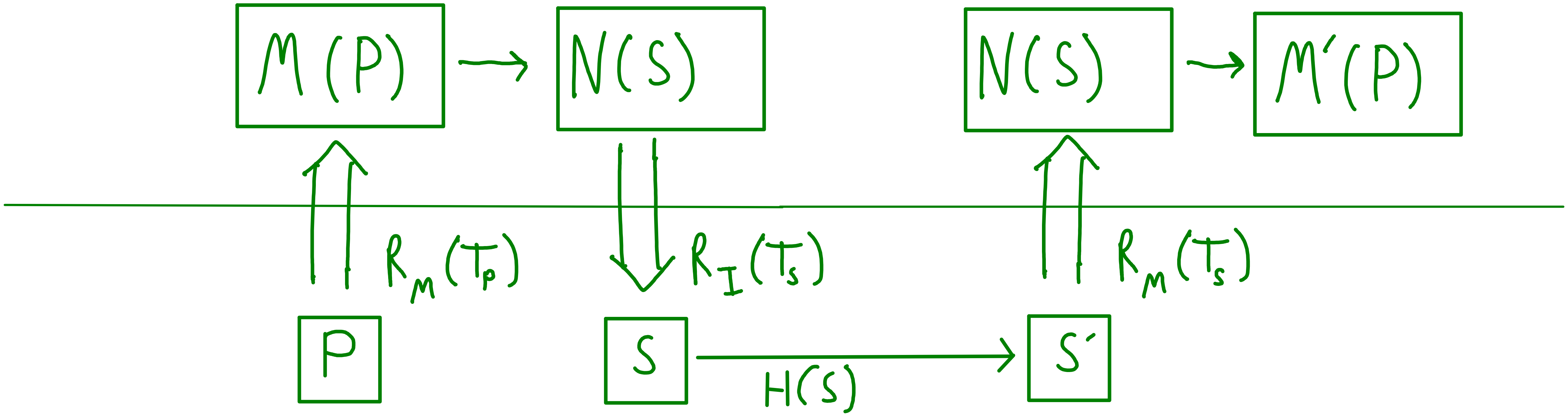
Surely now the definition depends on ill defined notions like intellect and intention?

What if a human discovers the program written by the cat, sees that it is useful and uses the result output by the computer. Is it then retroactively viewed as a computation?

Simulations

Claims that simple objects (like rocks) are computers is based on the idea that they simulate theselves. Is this the case using this framework?

For a physical system S simulating a system P



So for a system simulating itself (P=S) there are still encoding and decoding steps, and representations according to theories

What is simulated is the model of P, not P itself

So unless we have a model to simulate, and encode and decode in order to simulate it, a physical system cannot be said to simulate itself (it is just being itself)

Computation or experiment?

The authors then use more examples to confuse the reader

Some physical systems have been experimentally shown to give certain outputs given certain inputs

- Slime moulds have been found to compute minimum paths
- Encode a map by putting outflakes where the cities should be, and the slime will show you were to put the roads

They argue that this leads to only a phenomological understanding of the kind of situations probed in the lab

Without a proper understanding of the physical processes going on, we cannot trust the processing outside the experimental regime. So can this be called a computer?

- Surely this is true of all physical systems
- We can't completely trust any theory to be valid in all regimes, so is anything a computer?

Conclusion

Their definition seems to be that a physical system is computing when a user inputs an input, extracts an output, and trusts that the physical evolution in-between corresponds to the abstract evolution that the user cares about

Or:

> If there were no people there would be no teacups, even if there were teacup shaped objects. For "there are teacups" implies "there are things to drink tea from" which in turn implies "there are tea-drinkers".
>
> Bas van Fraassen - Scientific Representation