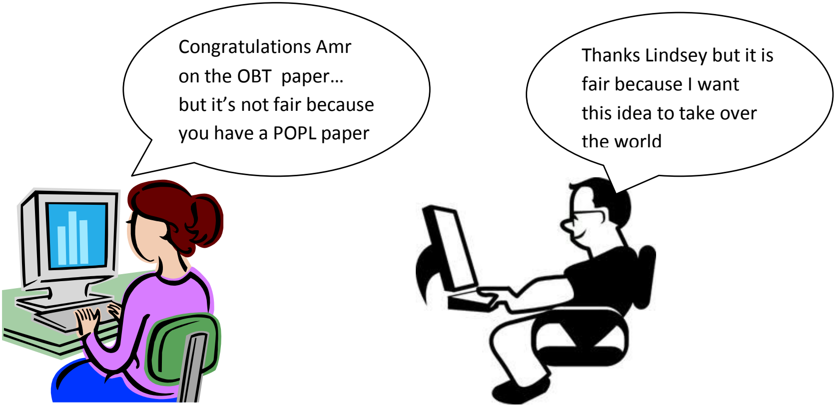
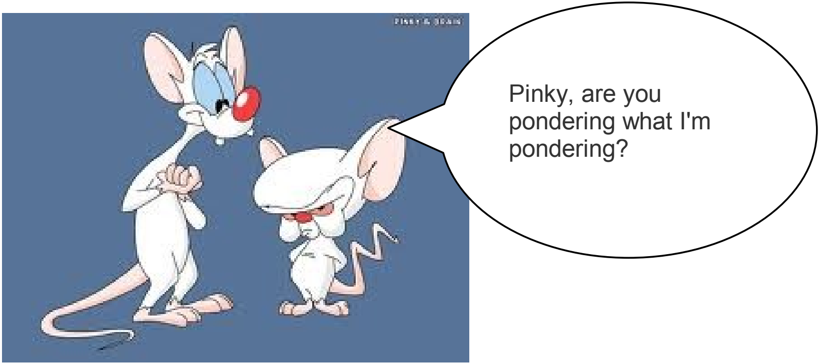
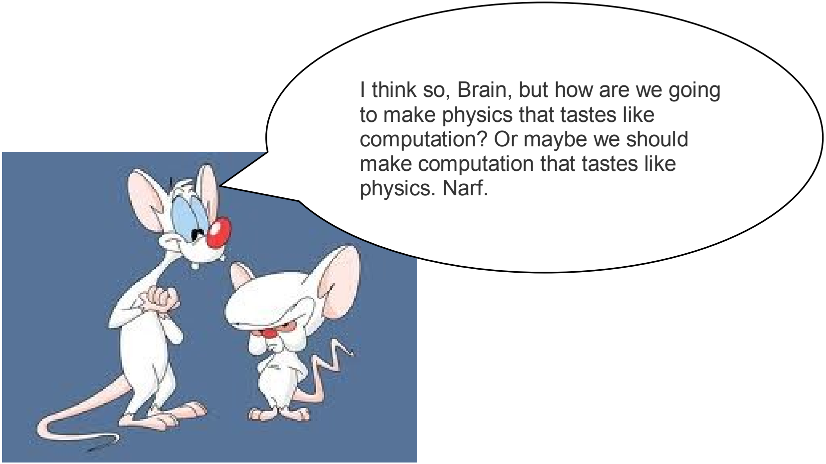
Embracing the Laws of Physics (OBT 2012)

Roshan P. James and Amr Sabry

January 28, 2012


Congratulations Amr on the OBT paper… but it’s not fair because you have a POPL paper
Thanks Lindsey but it is fair because I want this idea to take over the world


Pinky, are you pondering what I'm pondering?


I think so, Brain, but how are we going to make physics that tastes like computation? Or maybe we should make computation that tastes like physics. Narf.

So how are physics and computation related?

Our Origins: 1853

An Investigation of the Laws of Thought, on which are Founded the Mathematical Theories of Logic and Probabilities, G. Boole, 1853.

Opening sentence of Chapter 1:

> *The design of the following treatise is to investigate the fundamental laws of those operations of the mind by which reasoning is performed; . . .*

A few chapters later:

> ***Proposition IV.*** *That axiom of metaphysicians which is termed the principle of contradiction, and which affirms that it is impossible for any being to possess a quality, and at the same time not to possess it, is a consequence of the fundamental law of thought, whose expression is* $x^2 = x$.

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Quantum superposition!

Our Origins: 1936

On Computable Numbers, with an Application to the Entscheidungsproblem, A. Turing, 1936.

Opening sentence of Sec. 1:

> *We have said that the computable numbers are those whose decimals are calculable by finite means . . . the justification lies in the fact that the human memory is necessarily limited.*

Sec. 9:

> *I think it is reasonable to suppose that they can only be squares whose distance from the closest of the immediately previously observed squares does not exceed a certain fixed amount.*

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Locality!

More Connections

- Intuitionistism: The only truths are the ones that can be communicated with finite evidence.
- Parallel computation: Interaction with known (e.g., π-calculus) and unknown (e.g., cloud computing) partners.
- Chemical abstract machine, biologically-inspired computation, quantum computation, etc.

Linear Logic

Mostly known for careful accounting for resources. The physical connection is often forgotten.

> *In other terms, what is so good in logic that quantum physics should obey? Can't we imagine that our conceptions about logic are wrong, so wrong that they are unable to cope with the quantum miracle?*
>
> *[. . .]*
>
> *Instead of teaching logic to nature, it is more reasonable to learn from her. Instead of interpreting quantum into logic, we shall interpret logic into quantum (Girard 2007).*

Abstract Models of Computation / Logic

- Boole's argument: Boolean logic abstracts the "operation of the mind."
- Turing's argument: the Turing machine abstracts "a human calculator."
- and so on...

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- and so on. . .
- Feynman and others: Revisit our abstract models of computation / logics in view of the advances in physics.

Physical Principles for Programming Languages

Quantum Mechanics

It features connections to most other trends:

- quantum parallelism,
- account for resources (no-cloning and no-deleting theorems),
- observation only possible by interaction,
- reversible evolution like chemical reactions,
- . . . and is the most accurate physical theory known to us.

Quantum Computing

- not just about developing quantum programming languages
- connections to many areas of computer science and PL research

Physical Data

- modeled by a Hilbert space
- is associated with a locality; can be accessed concurrently
- data processing preserves distances
- creation or copying is expensive
- complete deletion is impossible (leaks into the environment)
- cannot be measured exactly; cannot be measured all at once; an interaction measures the attributes affected by the observation.

Physical Data — Data/Information/Types in PL

- modeled by a Hilbert space
- is associated with a locality; can be accessed concurrently — metric spaces; π-calculus; join-calculus
- data processing preserves distances — differential privacy; continuity
- creation or copying is expensive — linear logic; information effects (James and Sabry POPL 2012)
- complete deletion is impossible (leaks into the environment) — linear logic; information-flow security
- cannot be measured exactly; cannot be measured all at once; an interaction measures the attributes affected by the observation. — contracts

Good news

- All of these are computational effects of one kind or another.
- Have been studied in some form.

Good news — Bad News

- All of these are computational effects of one kind or another.
- Have been studied in some form.
- Study not foundational nor systematic.
  We can (and should) unify these threads!

Case Study: Contracts

A 2009 paper on contracts says: “contract monitoring should guarantee meaning reflection and meaning preservation, report contract violations faithfully, and behave idempotently.”

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- Meaning preservation: If unmonitored code produces an observable result, monitored should produce the same result or signal a contract violation.
- Faithful reporting: Code that follows a contract predicate can rely on the truth of the predicate.
- Being Idempotent: Enforcing the same contract twice is the same as enforcing it once.

Case Study: Contracts

- None of these properties hold if contract predicates can perform computational effects!
- Contracts can introduce their own errors!
- When checking expensive predicates, contracts can be probabilistic

Case Study: Contracts

If we take the position that contracts are like observers in quantum mechanics, then:

- being idempotent is consistent with quantum observers, but
- quantum observers may change the behavior, probabilistically
- quantum observers may be non-commutative

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If we take the position that contracts are like observers in quantum mechanics, then:

- being idempotent is consistent with quantum observers, but
- quantum observers may change the behavior, probabilistically
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- shouldn't be surprised that contracts may change the behavior
- provides us with guidelines about which effects are consistent with observation.

Conclusion

- Take effects seriously: “pure contracts on pure functions” might be a good starting point but don’t take it too seriously. Consider: continuations, concurrency, interaction, etc.

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- Accept that data is often incomplete, inconsistent, and evolving. Consider the effects of nondeterminism; probability, etc.
- Use the laws of nature to guide the laws of computing.
- Optional extra credit: Use the laws of computing to understand the laws of nature!