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Determinism

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ACM Transactions on Embedded Computing Systems, Volume 20, Issue 5 • July 2021 • Article No.: 38, pp 1–34 • https://doi.org/10.1145/3453652

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Lingua Franca
Determinism: every action is a consequence of preconditions and fixed rules.

Causation: preconditions cause the consequences.

Distaste for nondeterminism in the physical world follows from a distaste for uncaused action.
“All philosophers, of every school, imagine that causation is one of the fundamental axioms or postulates of science, yet, oddly enough, in advanced sciences such as gravitational astronomy, the word “cause” never occurs ... The law of causality, I believe, like much that passes muster among philosophers, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm.”

Bertrand Russell (1913)
“This is already enough to make strong the suspicion that a real understanding of determinism cannot be achieved without simultaneously constructing a comprehensive philosophy of science. Since I have no such comprehensive view to offer, I approach the task I have set myself with humility. And also with the cowardly resolve to issue disclaimers whenever the going gets too rough.”

Resolution of Alternatives

The essential questions:

When, how, and why are alternatives resolved?

These are three different questions!
Focus on *When Alternatives are Resolved*

Possible tiny universes:

**Deterministic**

```
nothingness → being1
  bang → being1
  tick → end1
```

```
nothingness → being2
  bang → being2
  tock → end2
```

**Nondeterministic**

```
nothingness → being
  bang → being
  tick → end1
```

```
being → end2
  tock → end2
```

Language:

(bang, tick)
(bang, tock)
It is impossible to tell *objectively* (by observation alone) which of these scenarios is true.

This follows from Robin Milner’s notion of *bisimulation relations between automata*.

It *is* possible to tell the difference with subjective, first-person, *interaction*, but not up to 100% confidence.
Given the *Model*, however, the difference is obvious.

Possible tiny universes:

**Deterministic**

- **nothingness**
  - **bang**
  - **being1**
    - **tick**
    - **end1**

**Nondeterministic**

- **nothingness**
  - **bang**
  - **being**
    - **tick**
    - **end1**
  - **tock**
    - **end2**

Language: *(bang, tick) (bang, tock)*
A **model** is *deterministic* if, given the initial *state* and the *inputs*, the model defines exactly one *behavior*.
Some Deterministic Models in Engineering Practice

Single-threaded imperative programs

```
void foo(int32_t x) {
    if (x > 1000) {
        x = 1000;
    }
    if (x > 0) {
        x = x + 1000;
    }
    if (x < 0) {
        panic();
    }
}
```

Instruction set architecture (ISA)


Synchronous digital logic

Images: Wikimedia Commons
The Value of Deterministic Models

• **Repeatability**
  – Same input, same outputs. **Testing.**
Some nondeterministic designs are untestable

NASA's Toyota Study (US Dept. of Transportation, 2011) found that Toyota software was “untestable.”

Possible victim of unintended acceleration
The Value of Deterministic Models

- **Repeatability**
  - Same input, same outputs. **Testing**.
- **Consensus**
  - Independent agents agree.
- **Predictability**
  - *Some* deterministic models are predictable.
Determinism Does Not Imply Predictability!

Lewis and MacGregor (2006) thought experiment:
• Two spheres colliding.
• Precision of initial conditions needed to predict behavior.
• Measure positions optically.
• Find the required wavelength of light.
• A single photon of such light would have “more energy than is currently posited for the entire universe in order to resolve the initial state of the system with precision sufficient to predict its behavior after just 35 collisions.”
Lorenz attractor:

$$\begin{align*}
\dot{x}_1(t) &= \sigma(x_2(t) - x_1(t)) \\
\dot{x}_2(t) &= (\lambda - x_3(t))x_1(t) - x_2(t) \\
\dot{x}_3(t) &= x_1(t)x_2(t) - bx_3(t)
\end{align*}$$

The error in $x_1$ and $x_2$ due to numerical approximation is limited only by the stability of the system.
Deterministic real-time scheduling results in chaos.

[Thiele and Kumar, EMSOFT 2015]

Fig. 15. Response time across jobs for the multi-resource scheduler with $R_s(i - 1) = 7.76$ and $R_s(i - 2) = 7.74$. 
The Value of Deterministic Models

- **Repeatability**
  - Same input, same outputs. **Testing.**
- **Consensus**
  - Independent agents agree.
- **Predictability**
  - *Some* deterministic models are predictable.
- **Fault Detection**
  - Correct behavior is well defined.
- **Simplicity**
  - One correct behavior for each input.
- **Unsurprising Behavior**
  - Boring is good.
- **Composability.**
  - Component behavior is clear; composition behavior too.
• **Abstraction**
  – Nondeterministic abstractions may be easier to understand.
Abstraction and Refinement

Abstraction

Refinement

Models

Models
The Value of *Nondeterministic* Models

- **Abstraction**
  - Nondeterministic abstractions may be easier to understand.

- **Uncertainty (about the world)**
  - Model something not fully understood (*scientific model*)

- **Uncertainty (about the design)**
  - Deferred design decisions (*engineering model*)
In *science*, the value of a *model* lies in how well its behavior matches that of the physical system.

In *engineering*, the value of the *physical system* lies in how well its behavior matches that of the model.

A scientist asks, “Can I make a model for this thing?”

An engineer asks, “Can I make a thing for this model?”

A Lingua Franca program is an *engineering model*, so its value depends on the ability of the physical system to match the model.
“Essentially, all models are wrong, but some are useful.”

Box and Draper (1987)

“Essentially, all system implementations are wrong, but some are useful.”

Lee and Sirjani (2018)
The Value of *Nondeterministic* Models

- **Abstraction**
  - Nondeterministic abstractions may be easier to understand.

- **Uncertainty**
  - Model something not fully understood (scientific model)

- **Deferred Design Decisions**
  - Uncertain specification (engineering model).

- **Security**
  - Unpredictability can be good.

- **Don’t Care**
  - Many behaviors are OK for the same input.

- **Surprising Behavior**
  - Boring is bad.
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Lingua Franca

The Coevolution
The Entwined Futures of Humans and Machines
Edward Ashford Lee