The Rationality of Escalation
an unexpected use of Coinduction in Economics

Pierre Lescanne

ENS de Lyon

LAP, 24 Sep 2014

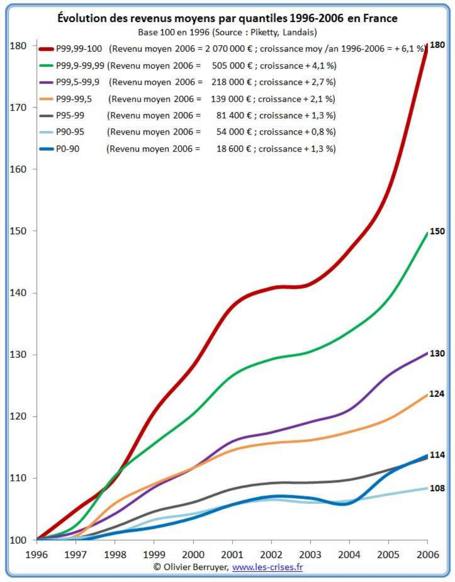
High-frequency trading

High-frequency trading (HFT) is a type of algorithmic trading, specifically the use of sophisticated technological tools and computer algorithms to rapidly trade securities.

HFT uses proprietary trading strategies carried out by computers to move in and out of positions in seconds or fractions of a second.

Wikipedia (2014)

Evolution of inequalities



South Sea Bubble

I can calculate the movement of the stars,
but not the madness of men.

claimed to be Newton's view
on the outcome of
the South Sea Bubble (1720).

The Dollar Auction

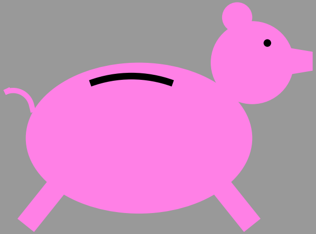
In 1971, in a paper called

> The Dollar Auction game:
> A paradox in noncooperative behavior and escalation

Martin Shubik described an infinite game.

The Dollar Auction *(the story revisited)*

For charity, an object is sold on an auction made a special way. There is a piggy bank (or a hat).



To bid, each person puts one euro in the piggy bank which is never returned to him.

The Dollar Auction: a game with costs

Assume that there are two bidders (*Alice* and *Bob*) and that the value of the object is v €.

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- the bidder who does not get the object has a cost of $v + n$.

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- It should be studied using tools designed for infiniteness.
  namely coinduction.

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- Escalation is irrational.

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Why this discrepancy?

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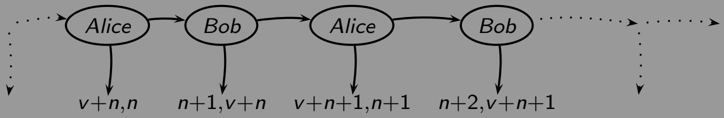

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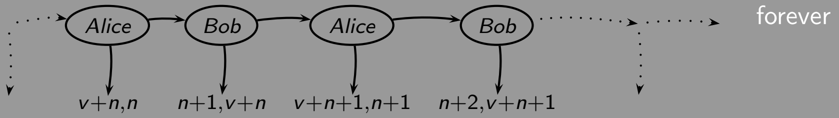
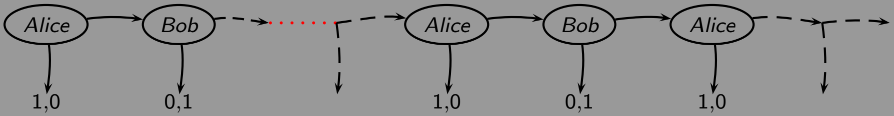


The dollar auction

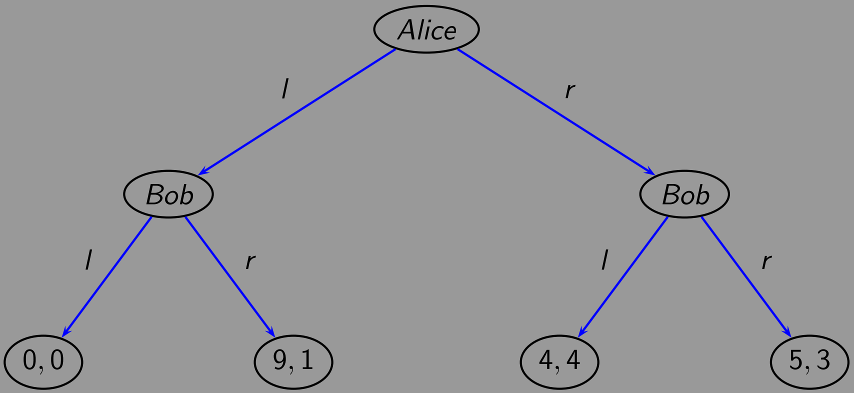
We will focuse on a simpler game (1 and 0, are costs)



The 0, 1 game

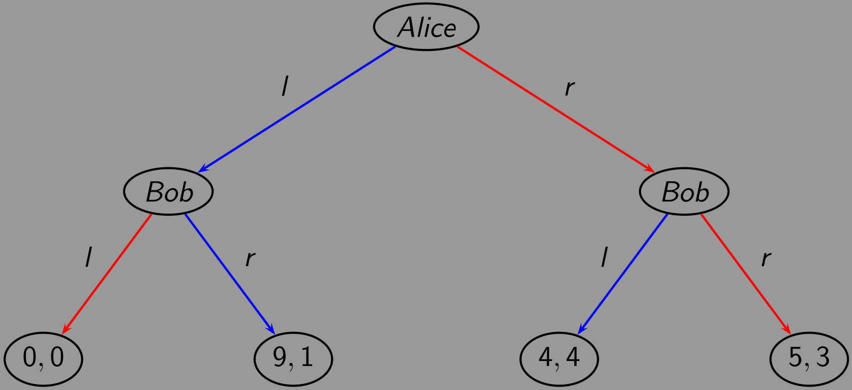
What is a *sequential* game?

A **sequential game** is described by a labeled tree



What is a *strategy profile* ?

A **strategy profile** is described by a labeled tree plus choices



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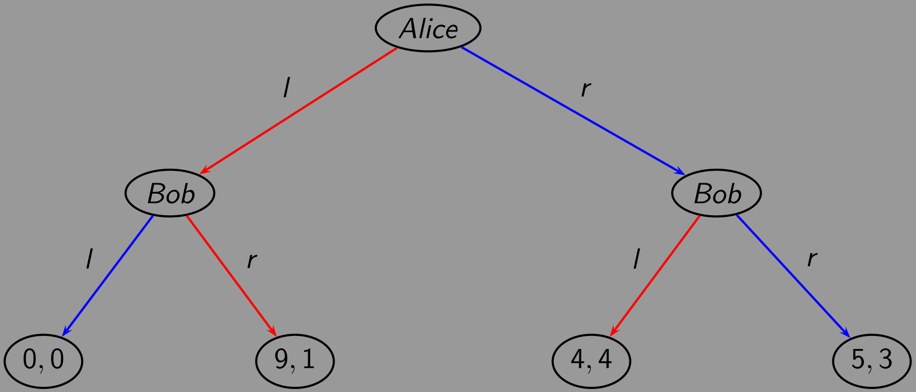
A **Nash equilibrium** is a strategy profile where if an agent changes alone his action he will get a utility which is not better.



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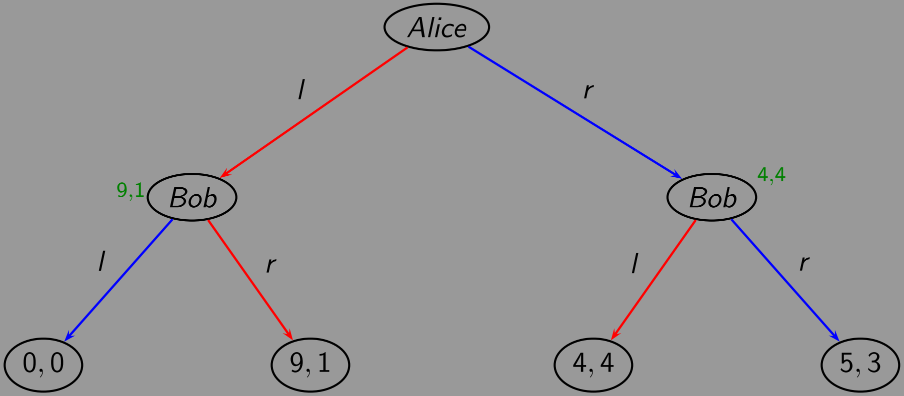

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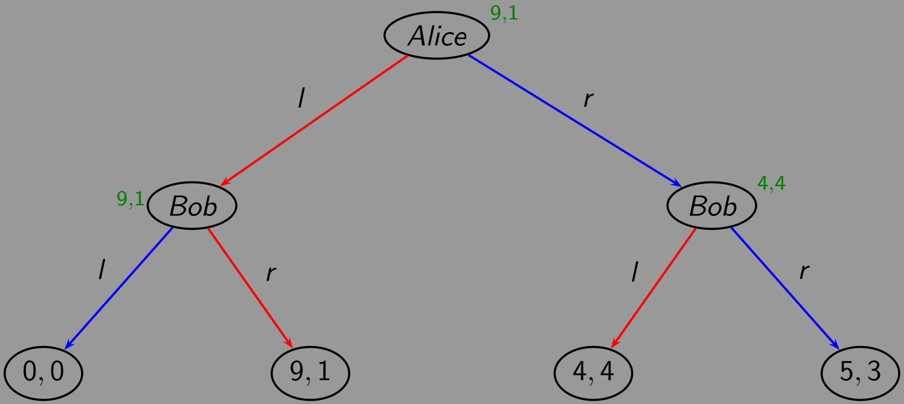

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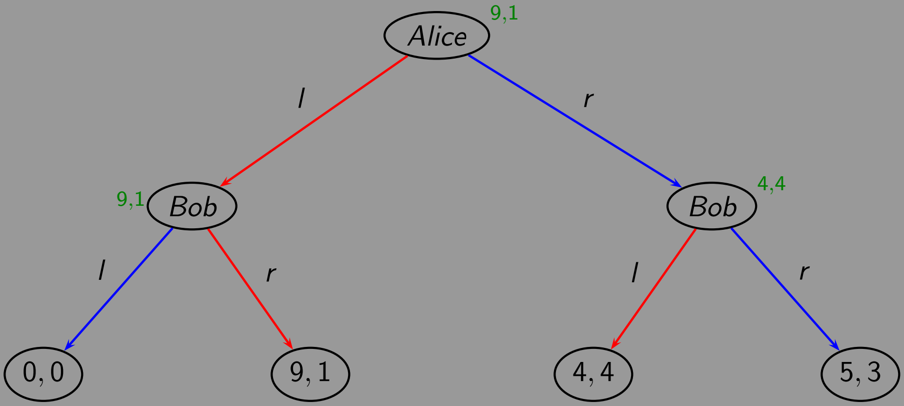

This way of computing this Nash equilibrium is called backward induction.

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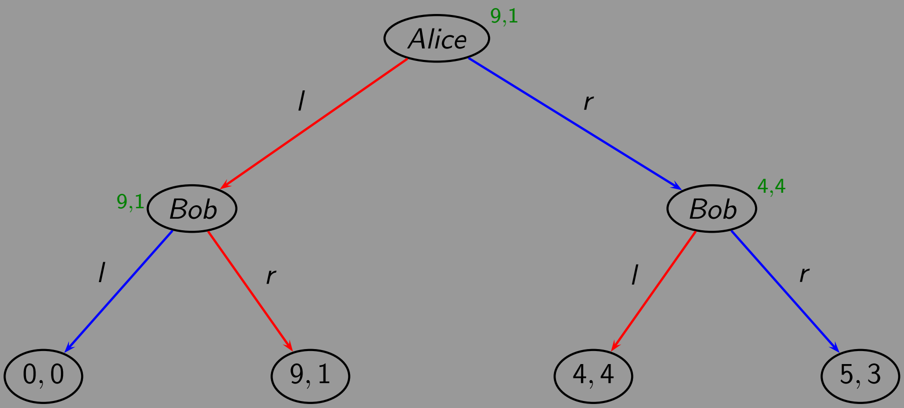

This Nash equilibrium is also called a backward induction equilibrium.

We are interested in infinite games,

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and to the extension of backward induction to infinite games.

Finite sequential games as inductive objects

A *finite sequential games* is described *by induction* from its subgames.

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Without loss of generality, we restrict to binary sequential games.

A binary finite sequential game is

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```
Inductive FinGame : Set :=
| gLeaf : Utility_fun → FinGame
| gNode : Agent → FinGame → FinGame → FinGame.
```

Utility and utility functions

Utility_fun is a function which associates a utility (a cost or a payoff) with an agent:

```
Definition Utility_fun := Agent → Utility.
```

A finite strategy profile is also an inductive

```
Inductive FinStratProf : Set :=
| sLeaf : Utility_fun → FinStratProf
| sNode : Agent → Choice → FinStratProf → FinStratProf
            → FinStratProf.
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A strategy profil is written $\ll f \gg$ and $\ll a, c, sl, sr \gg$.

From finite strategy profile to utility function

```
Fixpoint f2u (s:FinStratProf) :  Utility_fun :=
match s with
| ≪uf ≫   => uf
| ≪a, l, sl, sr≫  => (f2u sl)
| ≪a, r, sl, sr≫  => (f2u sr)
end.
```

Backward induction

On finite strategy profiles.

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Inductive BI: FinStratProf → Prop :=
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The concept of infinite strategy profile is also defined as a coinductive:

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CoInductive StratProf : Set :=
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It returns a value only on strategies which go eventually to a leaf.

The predicate *Leads to a leaf*

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Roughly speaking,
following the path given by the strategy profile one is lead to a leaf.

Existence and uniqueness

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Lemma *Existence_i2u*: $\forall$ $(a{:}Agent)$ $(s{:}StratProf)$,
$LeadsToLeaf\ s \rightarrow \exists\ u{:}Utility,\ i2u\ a\ u\ s.$

Lemma *Uniqueness_i2u*: $\forall$ $(a{:}Agent)$ $(u\ v{:}Utility)$ $(s{:}StratProf)$,
$LeadsToLeaf\ s \rightarrow i2u\ a\ u\ s \rightarrow i2u\ a\ v\ s \rightarrow u{=}v.$

The predicate *Always leads to leaf*

A strategy profile always leads to leaf,
if all strategy sub profiles lead to a leaf.

Also called *strongly convergent* and written $\Downarrow$

Proposition

$\Downarrow s = \Box(\downarrow s)$

SubGame Perfect Equilibria

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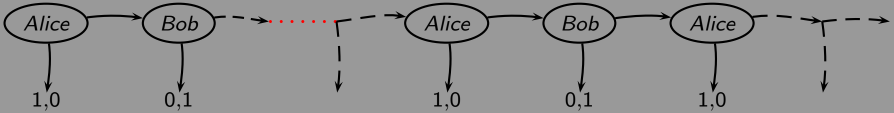
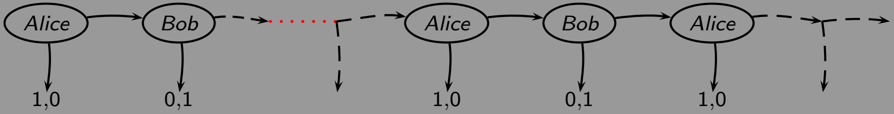


The 0, 1 game



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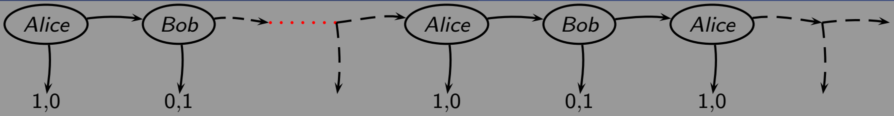

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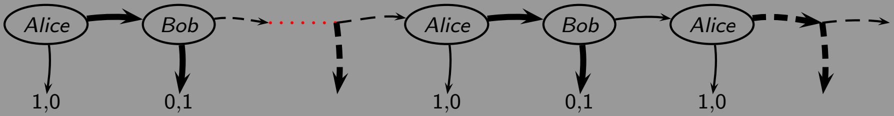
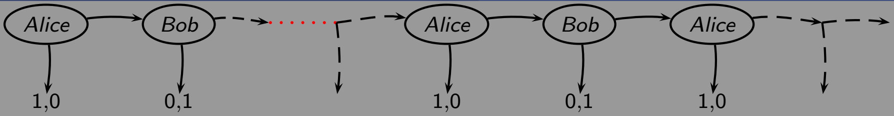
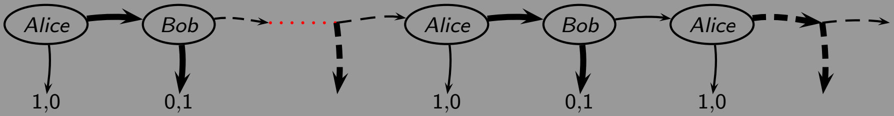


The strategy profile **Alice continues, Bob stops**



The 0, 1 game

0 and 1 are costs



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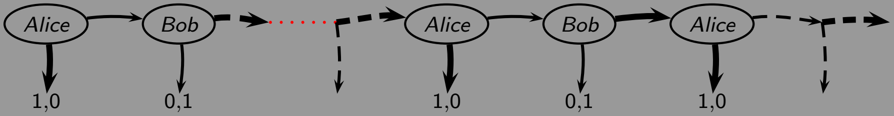

The strategy profile **Alice stops, Bob continues**

Two SGPE's

Theorem

The strategy profile **Alice continues, Bob stops** *is a SGPE.*

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The escalation

At each step Alice is rational if she continues.

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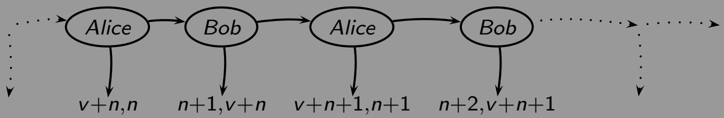
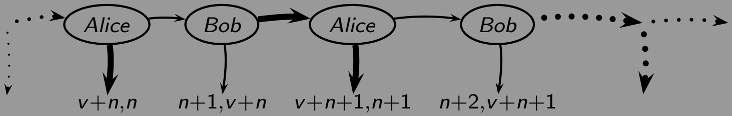
As a sequence of rational decisions, escalation is rational in 0, 1 game.

The *Dollar Auction* revisited



Alice abandons

In Shubik's game, we can prove that the strategy
Alice abandons and Bob continues



is a SubGame Perfect equilibrium.

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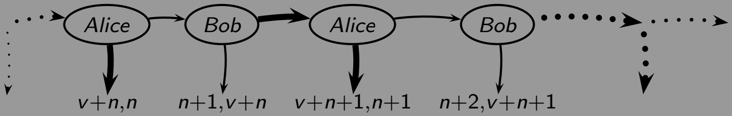
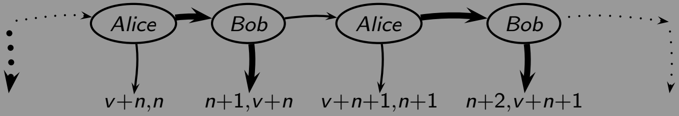


is a SubGame Perfect equilibrium.

Alice takes Bob's threat as credible and considers it is better to give up.

Bob gives up

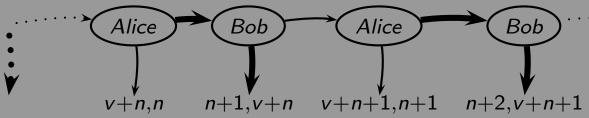
The strategy Alice continues and Bob gives up



is a SubGame Perfect Equilibrium.

Bob gives up

The strategy Alice continues and Bob gives up

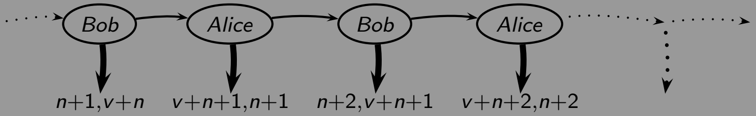


is a SubGame Perfect Equilibrium.

Bob takes Alice's threat as credible.

Always give up

The strategy always give up



is a not a SubGame Perfect Equilibrium and therefore not a Nash equilibrium.

Escalation in the Dollar Auction

At each turn if the agent continues she (he) is rational.

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Escalation is rational in the Dollar Auction game.

A book

A recent book addresses the new trends on rational thought.

K.E. Stanovich.
What Intelligence Tests Miss: The Psychology of Rational Thought.
Yale University Press, 2010.

Two levels of rationality

- Algorithmic mind: reasoning based on inferences and deduction.

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- Coalgebras and coinduction are the right tools for rethinking of economics.