Measuring Financial Relationships

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Office of Financial Research

Institute for Pure and Applied Mathematics (IPAM)

Workshop on Forensic Analysis of Financial Data

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Network Measurement

Mila Getmansky Sherman

U. Massachusetts

Ayeh Bandeh-Ahmadi
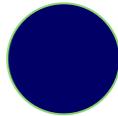
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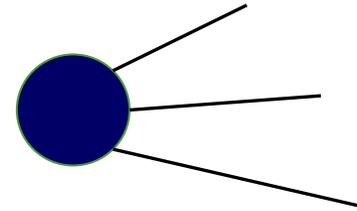## Financial Contracts as Automata

Oliver Goodenough

Vermont Law School and OFR

Why Does It Matter?

"4-L" Club – Billio, Getmansky, Lo and Pellizon (2012):

Leverage

Losses

Linkages
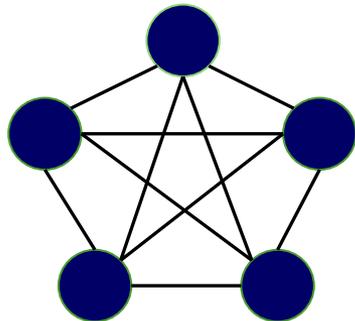
Liquidity

Image source : OFR analysis

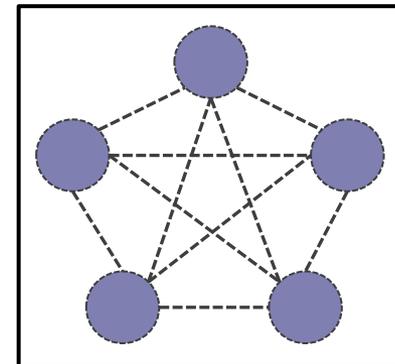OFFICE OF FINANCIAL RESEARCH

Firm-level financial statements

Highly standardized

- FASB
- GAAP
- Basel capital rules

Backward looking

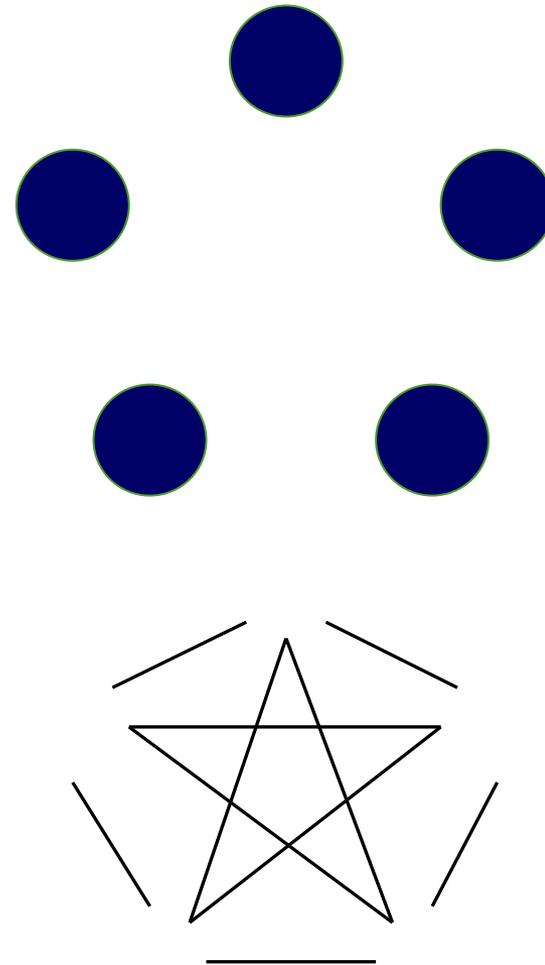- Historical/fair value
- Monovalent

Market transaction information

Pre-trade transparency

- Quotes and spreads
- Limit orders

Post-trade transparency

- Transaction prices
- Volumes

Direct measurement matters

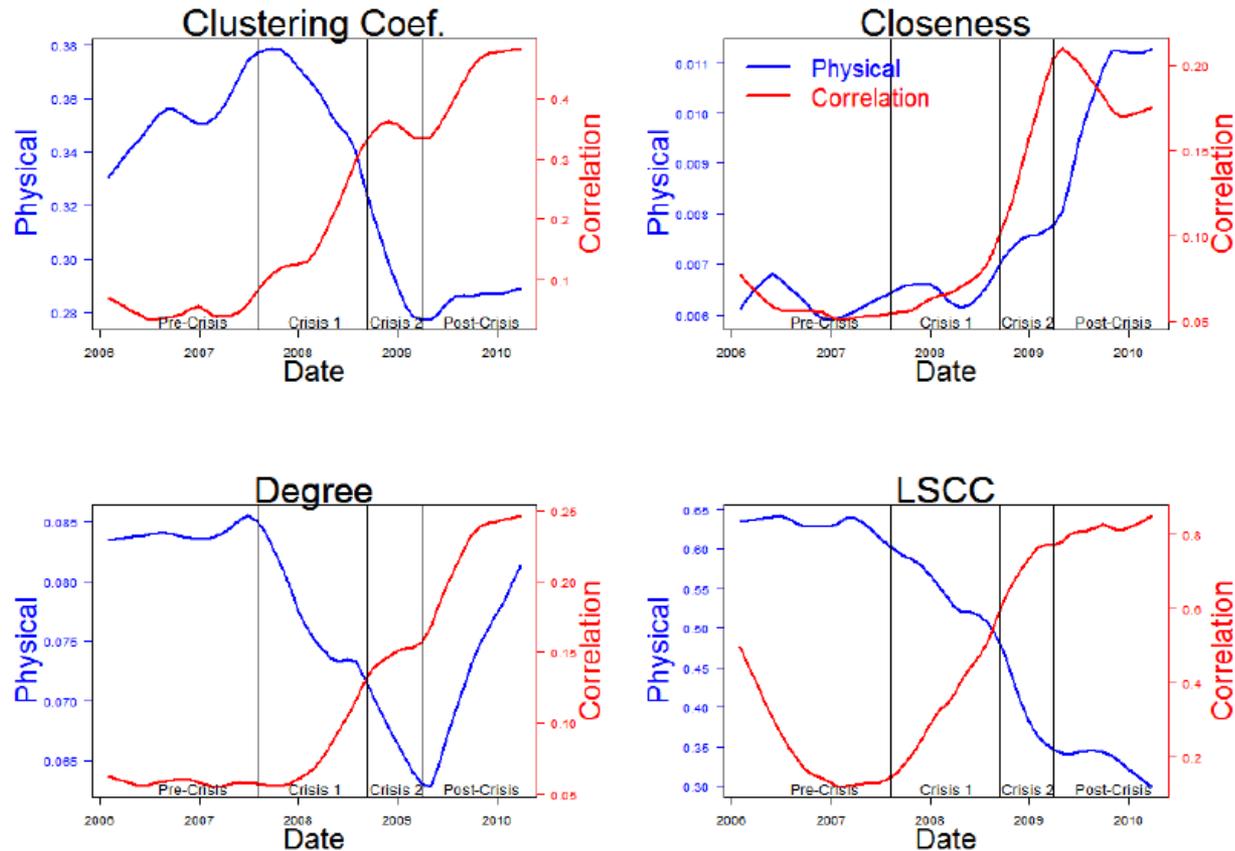Brunetti, Harris, Mankad & Michailidis (2015) **"Interconnectedness in the Interbank Market"**

Image source : Brunetti, Harris, Mankad, and Michailidis (2015)

Strategic network formation

- Counterparty graphs are non-random
  - Simple Erdös-Rényi is inadequate
- Core-periphery topology, for example
  - Capitalization requirements
  - Dealer monopoly unstable
  - Conflict-of-interest rules

Regulatory constraints on edge formation

- Chartering – permissible activities
- Volcker Rule
- SEC Rule 2a-7 for money funds

Endogenous forces

- Investment mandates and "objectives"
  - Leverage limits, use of derivatives, etc.
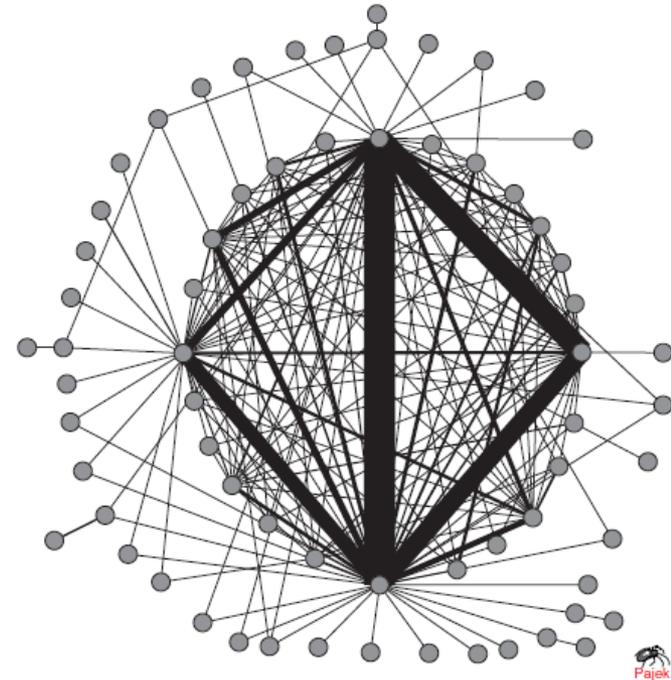- Risk reduction procedures
  - Netting and novation

Image source : Soramäki, Bech, Arnold, Glass, and Beyeler (2007)

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Money funds -- seeking yields and seeking safety in 2011

Chernenko & Sunderam (2014) **"Frictions in Shadow Banking"**
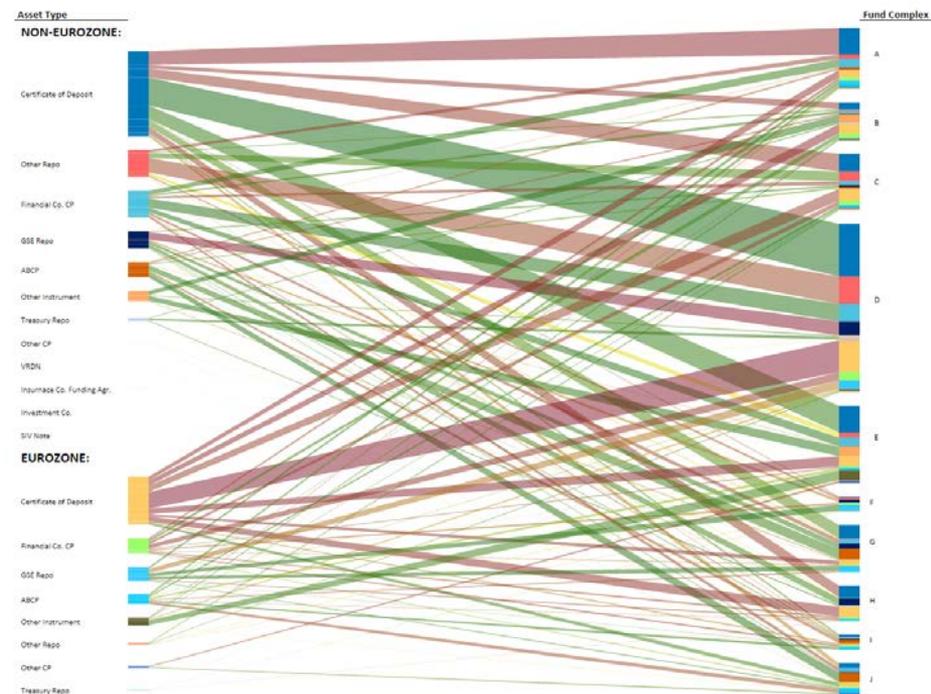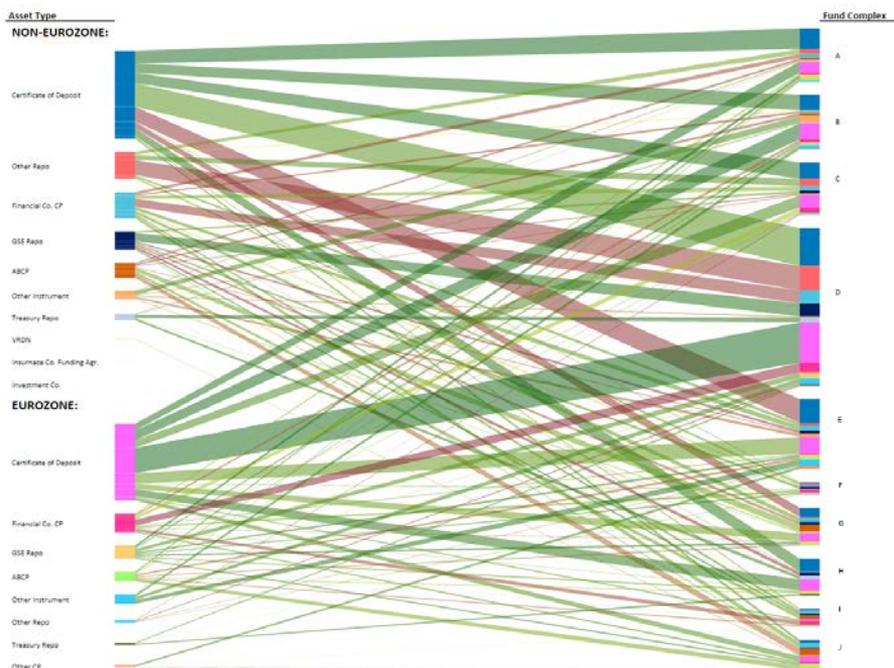
Pre-downgrade (June)

Post-downgrade

Image source : SEC N-MFP, OFR analysis

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Ownership Hierarchies

- Directed acyclic graph
- Definition of "ownership"
- Evolving over time
- Wells Fargo BHC (pruned), between 2006 and 2010:

  - 🟢 New since 2006
  - 🔴 Gone since 2006
  - ⚫ Always present

Some statistics:

- Nodes (pruned):   478
- Diameter (dir.):   9
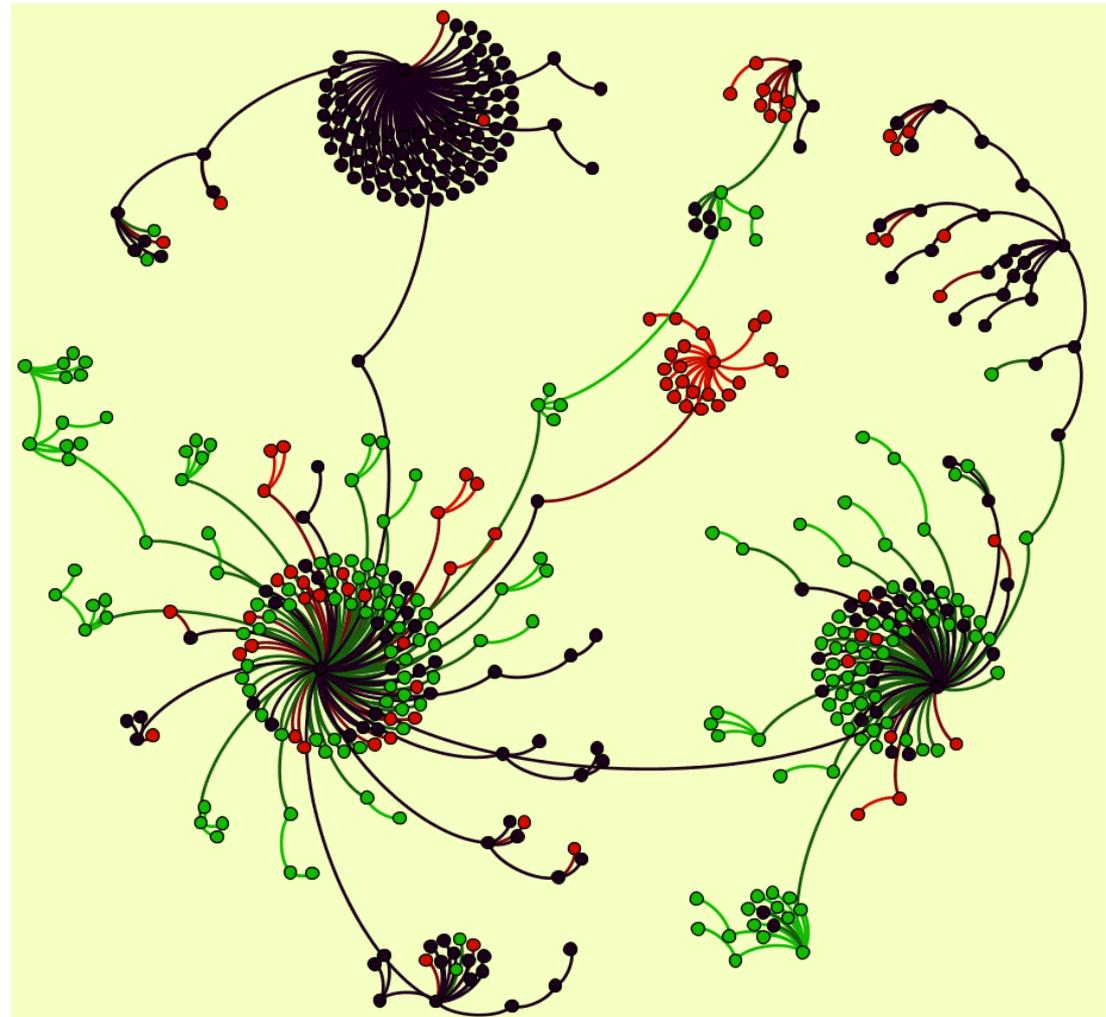- Avg. path length: 2.233
- Modularity: 0.811
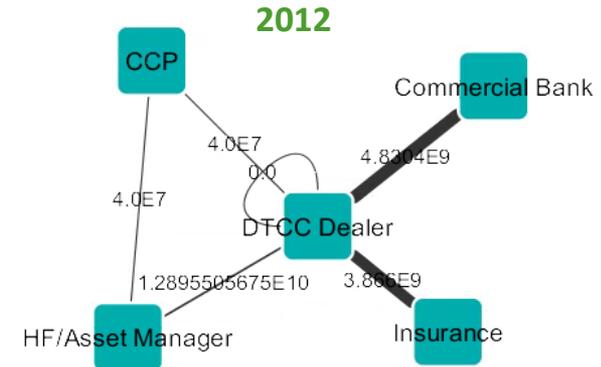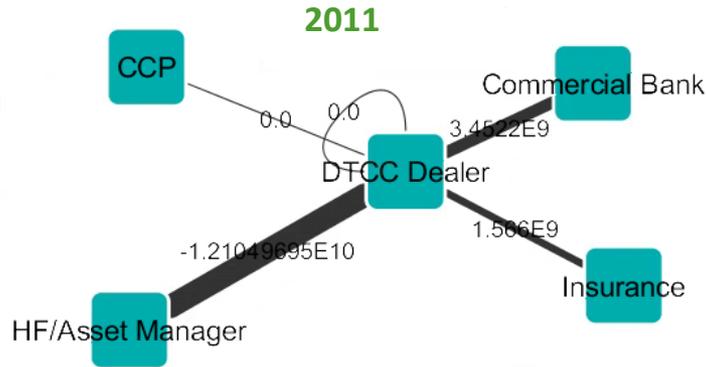

Image source : FFIEC (2015), OFR analysis

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Accumulating Concentrations: CDX.NA.IG.9

- ## Net positions

- ## Absolute value of positions

Image source : OFR analysis

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Net positions aggregated by counterparty types

- Multiple CDS maturities; trading on Jan. 1, 2010 – Aug. 8, 2014

Image source : OFR analysis

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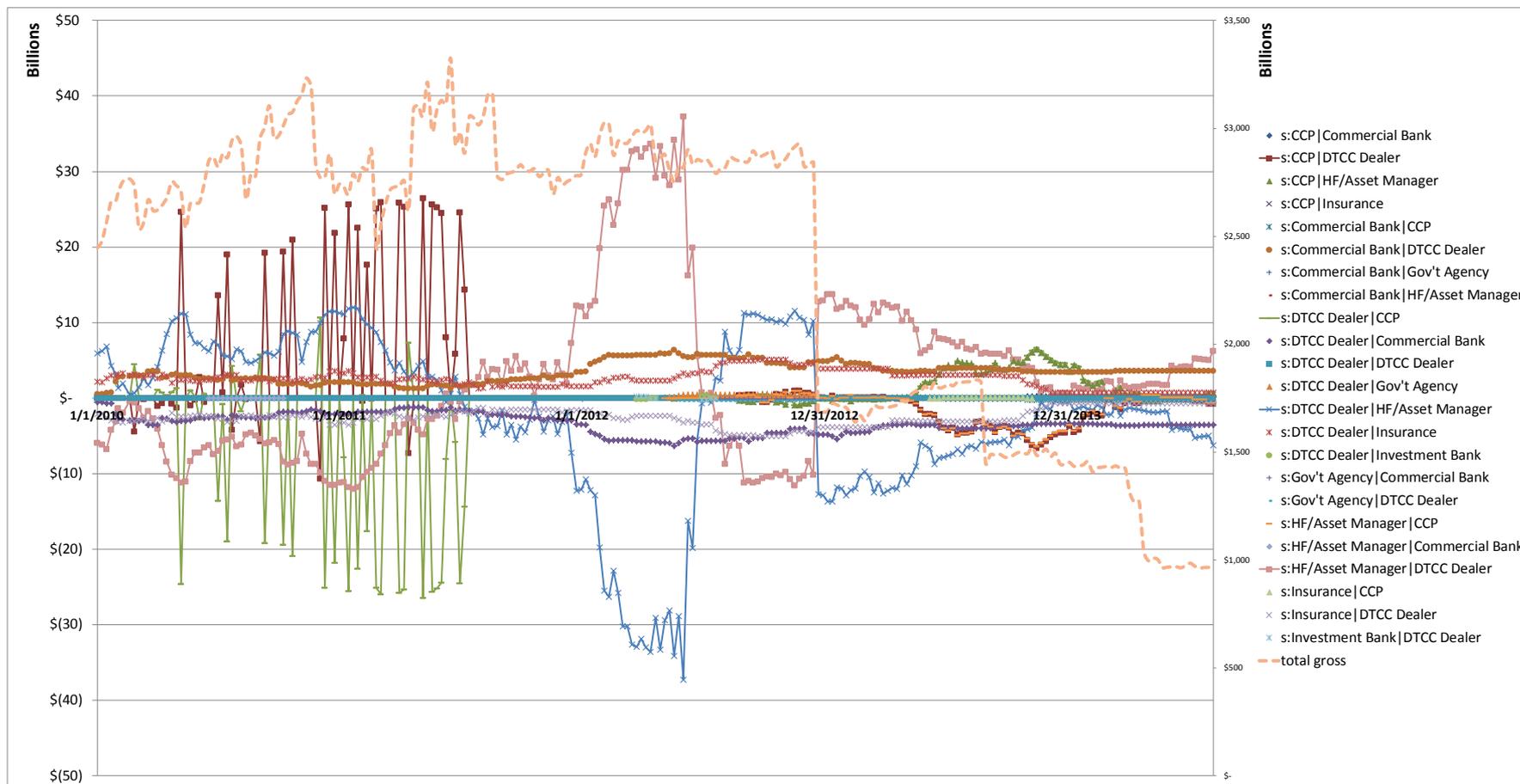
Gross Positions in CDX.NA.IG.9

Gross positions aggregated by counterparty types

- Multiple CDS maturities
- Jan. 1, 2010 – Aug. 8, 2014
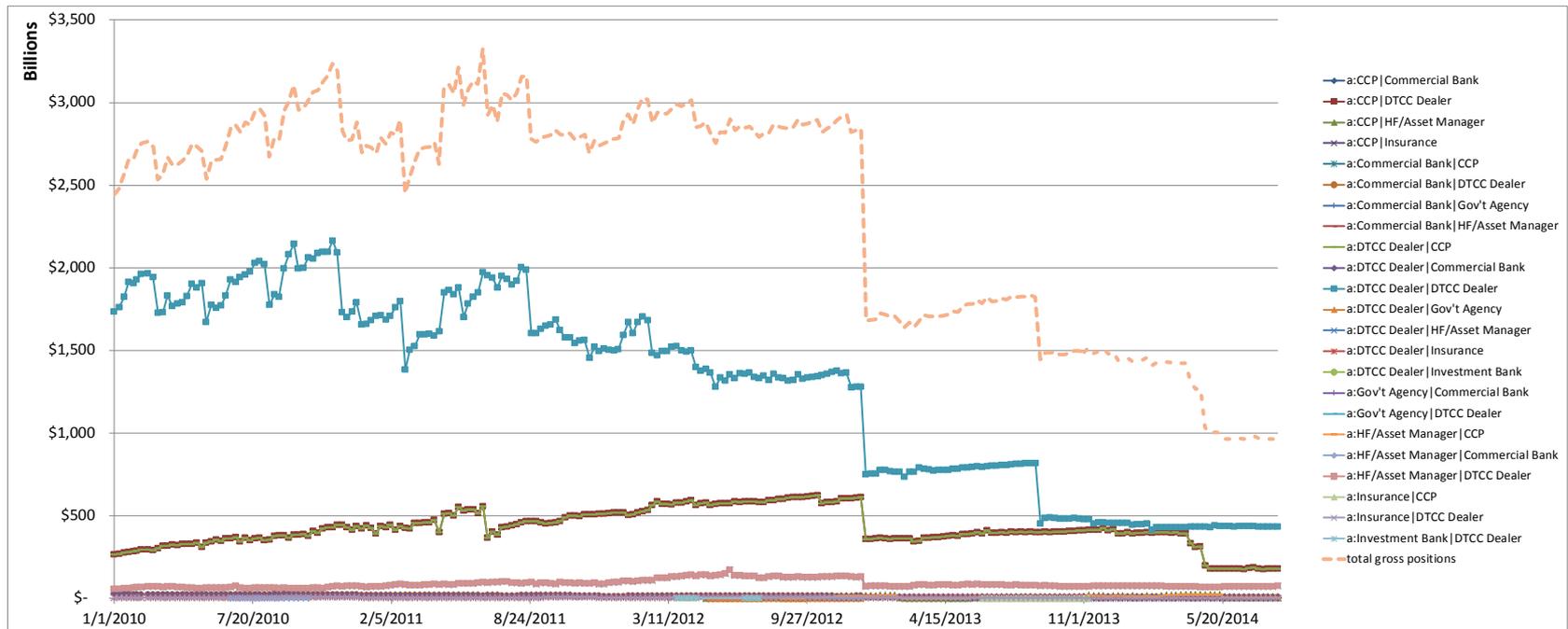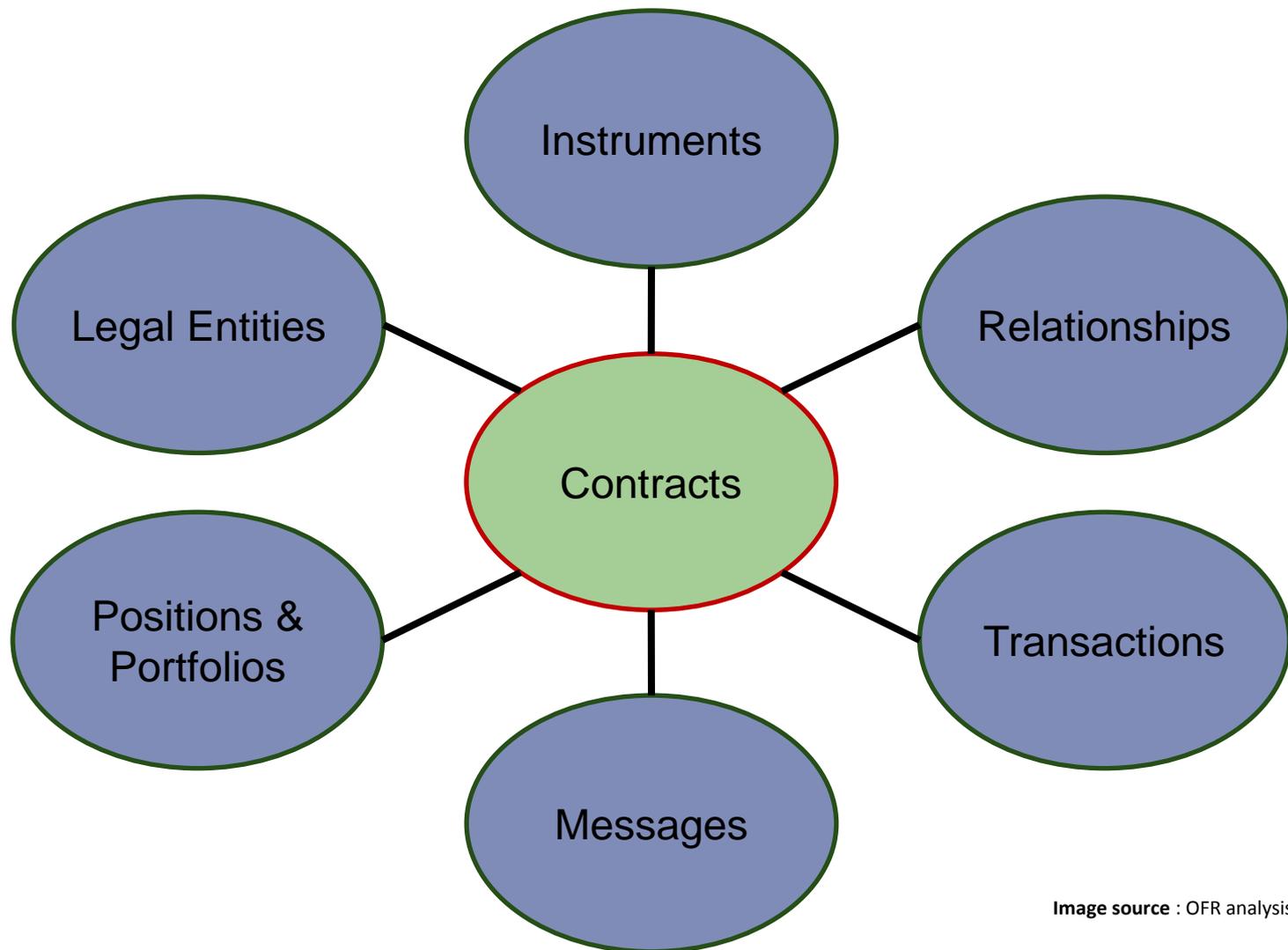
Image source : OFR analysis

Image source : OFR analysis

Simple two-page loan contract

1. The Loan: $1000, June 1, 2014
2. Repayment:
   - Payment 1, due June 1, 2015: $550
   - Payment 2, due June 1, 2016: $525
3. Representations and Warranties
4. Covenants
5. Events of Default:
   - Borrower fails to make timely payment
   - Reps or warranties prove untrue
   - Borrower fails any covenants
   - Borrower files for bankruptcy
6. Acceleration on Default
7. Choice of Law
8. Amendments and Waivers
9. Courts and Litigation
10. Time of the Essence; No Pre-Payment
11. Notices

Image source : OFR analysis

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Deterministic Finite Automaton (DFA)

- **A deterministic finite automaton (DFA) is defined by a 5-tuple:**
  - Finite set of states (Q)
  - Finite set of input symbols (information/events) called the alphabet (Σ)
  - Transition function ($\delta : Q \times \Sigma \rightarrow Q$)
  - Start state ($q_0 \in Q$)
  - Set of accept (end) states ($F \subseteq Q$)

- **Three representations (at least):**
  - Lists (of Q, Σ and δ)
  - Graphical (depiction of states and transitions among them)
  - Regular expression (shorthand grammar of acceptable event sequences)

State Space (27)

State	Label	Natural Language Consequences and Correlates (Λ)	Sec
start Φ	Start	Contract is fully specified; key information (payment dates, notice addresses and procedures, choice of law and dispute process) delivered	7, 9, 11
q0 Φ	Active contract	Contract is fully signed/executed	
q1 Φ	Principal Requested	Borrower's has requested and awaits $1,000	1
P1 Φ	Pmt 1 accruing		
P1d Φ	Pmt. 1 due		
P2 Φ	Pmt 2 accruing		
P2d Φ	Pmt. 2 due		
Dl	Default (lender)	Lender has failed to deliver principal	5
Acc1	Payments 1 and 2 Accelerating	Accelerated payment due is $1075	6
Acc2	Payments 2 Accelerating	Accelerated payment due is $525	6
Db0_1	Default (borr.) payment missed	Borrower has failed to make first payment in a timely fashion, and should be notified	5
Dbcv_1	Default (borr.) Covenant	Borrower violates covenant(s), and should be notified	5
Dbrw_1	Default (borr.) Reps/Warr.	Borrower breaches reps. and/or warranties; should be notified	5
Dbbkr_1	Default (borr.) Bankruptcy	Borrower files for bankruptcy or insolvency; should be notified	5
Nb0_1 ⊥	Borr. notified of payment default	Borrower has 2 days to pay, or all payments accelerate	5
Nbnpd_1 ⊥	Borr. notified of general default	Borrower has 2 days to pay, or all payments accelerate	5
Db0_2	Default (borr.) payment missed	Borrower has failed to make first payment in a timely fashion, and should be notified	5
Dbcv_2	Default (borr.) Convenant	Borrower violates covenant(s), and should be notified	5
Dbrw_2	Default (borr.) Reps/Warr.	Borrower breaches reps. and/or warranties; should be notified	5
Dbbkr_2	Default (borr.) Bankruptcy	Borrower files for bankruptcy or insolvency; should be notified	5
Nb0_2 ⊥	Borr. notified of payment default	Borrower has 2 days to pay, or all payments accelerate	5
Nbnpd_2 ⊥	Borr. notified of general default	Borrower has 2 days to pay, or all payments accelerate	5
xT *	TERM	Contract is fulfilled in accordance with its terms	
xL *	LIT	A legal action is brought to enforce, interpret or otherwise deal with the agreement in the state courts of the State of New York located in New York County and that the results of this action will replace the computation of the contract	9
xC *	CANC	Contract is canceled due to the passing of time beyond the statute of limitations or canceled because of modification or termination by mutual agreement of the parties	8
Crisis1	Crisis1 – accel. payments not made	Payments accelerated, but borrower has not responded	6
Crisis2	Crisis2 – accel. payments not made	Payments accelerated, but borrower has not responded	6

Φ States on the "happy" path of the contract lifecycle
⊥ Default states
* Terminal states

Event Alphabet (20)

ID	Label	Natural Language Event Specification	Section
A	Contract signed	Contract is signed to bind all parties	
B	1 Day passes since last event	June 1, 2014 passes	1
C	Money requested	Borrower gives request for loan of $1,000	1
D	Lawsuit	A legal action is brought to enforce, interpret or otherwise deal with the agreement in the state courts of the State of New York located in New York County.	
E	Statute of limitations	June 1, 2020 passes – the Statute of Limitations on debt obligations in New York is six years	
F	Principal advanced	Lender advances $1,000 no later than June 2, 2014	1
G	June 1, 2015 passes	Payment 1 due on June 1, 2015	2(a)
H	Reps/warr.	The Borrower's assets exceed its liabilities as determined under an application of the FASB rules of accounting	3, 5(b)
I	Covenant	The Borrower fails to make a timely payment of an amount of state or federal tax	4, 5(c)
J	Bankruptcy	The Borrower files for bankruptcy or insolvency under any applicable federal or state law	
K	Notice given	Notice given to Borrower of a failure to make timely payment of an amount due to Lender under this agreement	5
L	Notice given of general default	Notice given to Borrower of an event of default other than a failure to make timely payment of an amount due	5
M	Payment default cured	A payment-related event of default is cured	5
N	General default cured	A non-payment related event of default is cured	5
O	2 Days pass since last event	Two days elapse since last event/notice	5
P	June 1, 2016 passes	Payment 2 is due on June 1, 2016	2(b)
Q	Payment made $550		
R	Payment made $525		
S	Payment made $1075		
T	Cancel or modify	Contract in this form is canceled because of modification or termination by mutual agreement of the parties	8

Transitions (45)

Initial State	Event	Resulting State
start Φ	A	q0
q0	B	xT
q0 Φ	C	q1
q1	B	Dl
Dl	D	xL
Dl	E	xC
q1 Φ	F	P1
P1 Φ	G	P1d
P1d	B	Db0_1
P1	H	Dbrw_1
P1	I	Dbcv_1
P1	J	Dbbkr_1
Db0_1	K	Nb0_1
Dbcv_1	L	Nbnpd_1
Dbbkr_1	L	Nbnpd_1
Dbrw_1	L	Nbnpd_1
Nb0_1	Q	P2
Nbnpd_1	N	P1
Nb0_1	O	Acc1
Nbnpd_1	O	Acc1
Acc1	B	Crisis1
Acc1	S	xT
Crisis1	E	xC
Crisis1	D	xL
Crisis1	S	xT
P1d Φ	Q	P2

Initial State	Event	Resulting State
P2 Φ	P	P2d
P2d	B	Db0_2
P2	H	Dbrw_2
P2	I	Dbcv_2
P2	J	Dbbkr_2
P2d Φ	R	xT
Db0_2	K	Nb0_2
Dbcv_2	L	Nbnpd_2
Dbbkr_2	L	Nbnpd_2
Dbrw_2	L	Nbnpd_2
Nb0_2	R	xT
Nbnpd_2	N	P2
Nb0_2	O	Acc2
Nbnpd_2	O	Acc2
Acc2	B	Crisis2
Acc2	R	xT
Crisis2	E	xC
Crisis2	D	xL
Crisis2	R	xT

Φ Transitions along the "happy" path of the contract lifecycle
As noted above, only the transitions that result in a change of states are noted here; all un-noted transitions result in the state being unchanged.

State Space (27)

Q

Event Alphabet (20)

Σ

Transitions (45)

δ

Image source : OFR analysis

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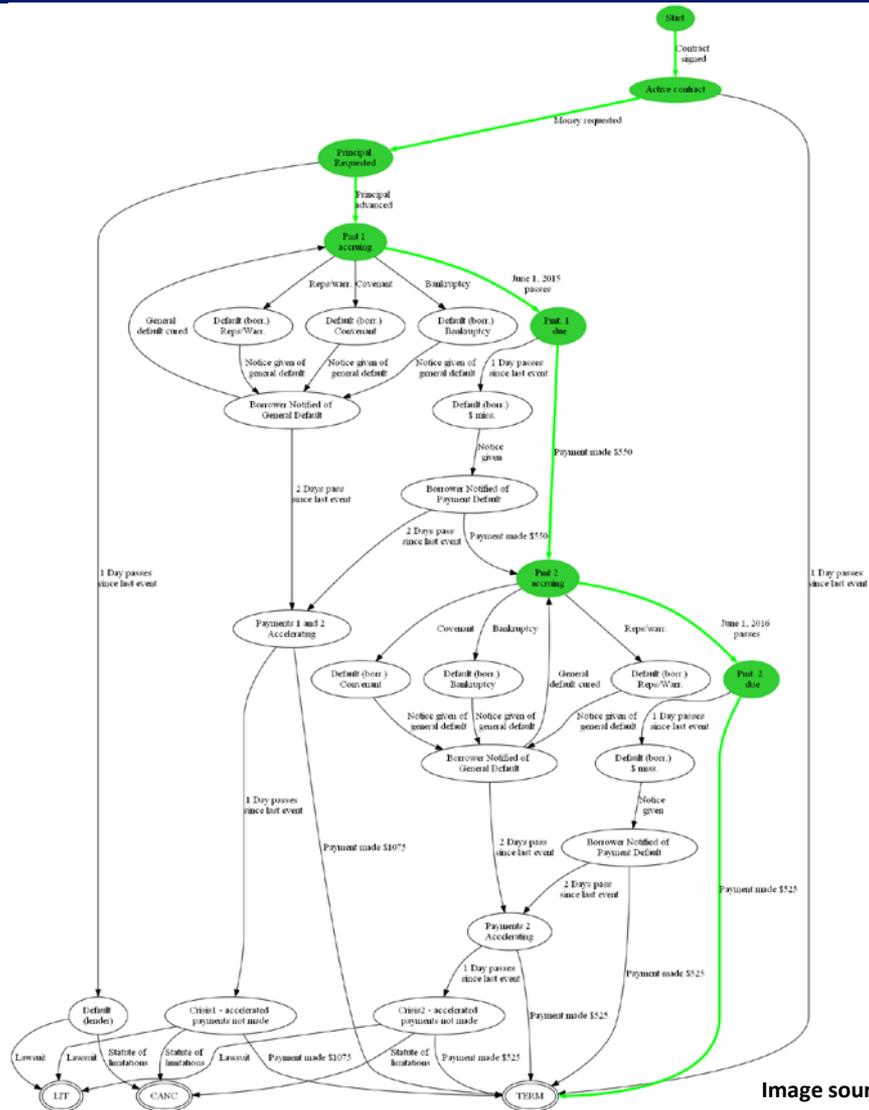
Image source: OFR analysis

DFA as a chain of event and consequence:

- Start state (q_0) at the top
- Terminal states (3) at bottom
- "Happy" or intended path traced in green
- More "interesting" ramifications traced in black

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Regular expressions list the "acceptable" event sequences under the DFA

- Uses a compact shorthand notation
- Equivalent (without labels) to the tabular and graphical representations
- Natural measure of complexity (i.e., length of the regex)

`A(B|CB[ED])|`   *Rapid demise*

`ACF(G(BK)?)QPR|`   *Happy path*

`ACF([HIJ]LN)*(GBK|[HIJ]L)O(S|B[DES])|`   *Unhappy* 1

`ACF(G(BK)?)Q([HIJ]LN)*(PBK|[HIJ]L)O(R|B[RED])`   *Unhappy* 2

- **Basic Results on Complexity**
  - DFAs enforce the Markov (or Myhill-Nerode) property – *state is "memoryless"*
    - The DFA "lives in the moment" – all transitions are one-step-ahead actions
  - Computational complexity is manageable:
    - Constrained by the Myhill-Nerode condition
    - Measurable by the descriptional complexity of the regular expression
  - The law appears to have evolved this constraint organically
    - Sorcerer's Apprentice problem

- **Assessing Complexity**
  - The complexity of actual contracts is (in theory) rigorously measurable
  - The computational "inefficiency" of a contract is measurable:
    - Measure the contract's actual complexity, C
    - Reduce the contract's DFA to its theoretical minimum and measure that complexity, C^*
    - The difference, $\Delta C = (C{-}C^*)$, is a measure of "unnecessary" complexity

Economic and policy forces

- Privacy and confidentiality
- Data management costs
- Incentive problems

Co-evolution of analytics and data requirements

- Data requirements depend on the analytical models the data will feed.
- Analytical models evolve in response to results obtained from available data.

Avoiding data "stovepipes" via data abstraction

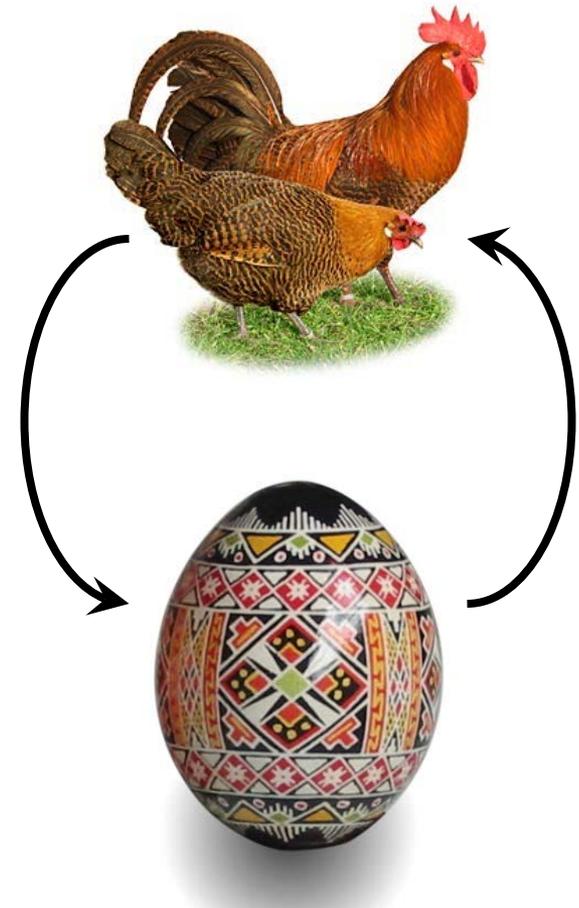- Policy-mechanism separation
- Role-and-context-based access control

Image source : Stijn Ghesquiere (2004), www.wikipedia.org

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Fundamental Rule of Data Collection

Endogenous Myopia

Firms will not disclose their positions

Myopia: firms' visibility distance ≤ 1

➔ Role for public supervision
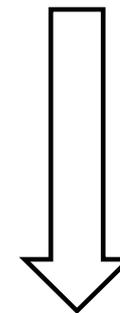
State-dependent Data Requirements

Supervisory needs increase under:

– Crisis monitoring

– Failure resolution

– Forensic investigation

Shneiderman's Visualization Mantra

– Overview first

– Zoom and filter

– Details on demand

System-wide
Data Collection

Requires

Data Standards

Thanks!

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