

# Measuring Financial Relationships

Mark D. Flood

*Office of Financial Research*

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**Institute for Pure and Applied Mathematics (IPAM)**

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**Views and opinions expressed are those of the speaker and do not necessarily represent official OFR positions or policy.**

## Network Measurement

Mila Getmansky Sherman

*U. Massachusetts*

Ayeh Bandeh-Ahmadi

*Office of Financial Research*

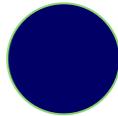
## Financial Contracts as Automata

Oliver Goodenough

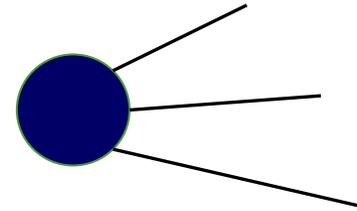
*Vermont Law School and OFR*

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

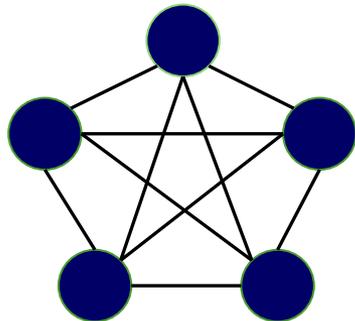
Leverage



Losses



Linkages



Liquidity

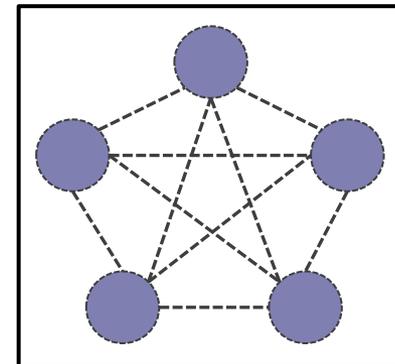


Image source : OFR analysis

## Firm-level financial statements

### Highly standardized

- FASB
- GAAP
- Basel capital rules

### Backward looking

- Historical/fair value
- Monovalent

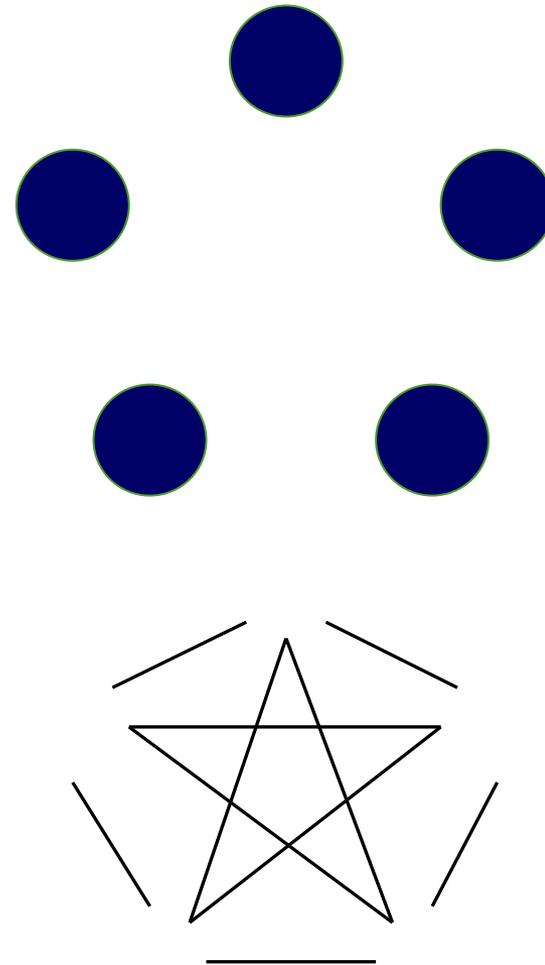
## Market transaction information

### 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”

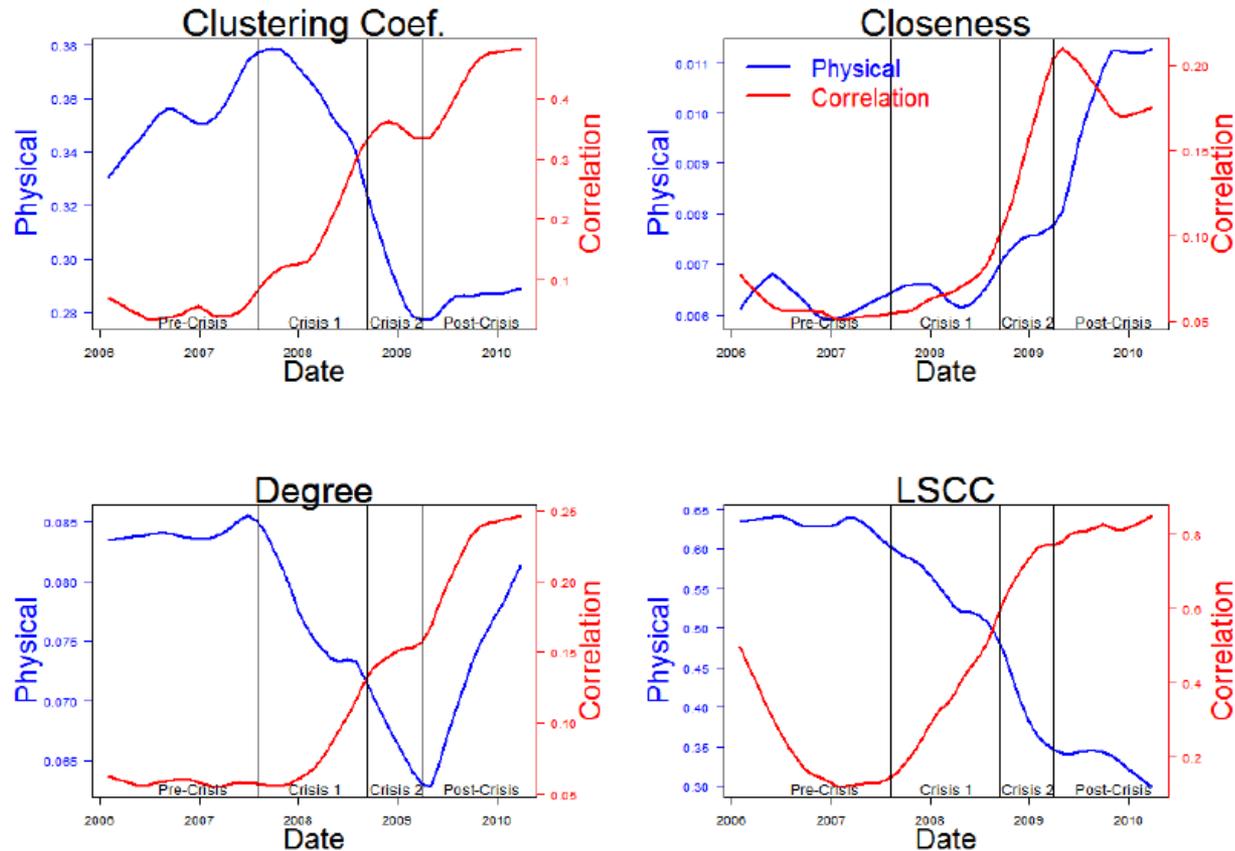


Image source : Brunetti, Harris, Mankad, and Michailidis (2015)

## Strategic network formation

- Counterparty graphs are non-random
  - Simple Erdős-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

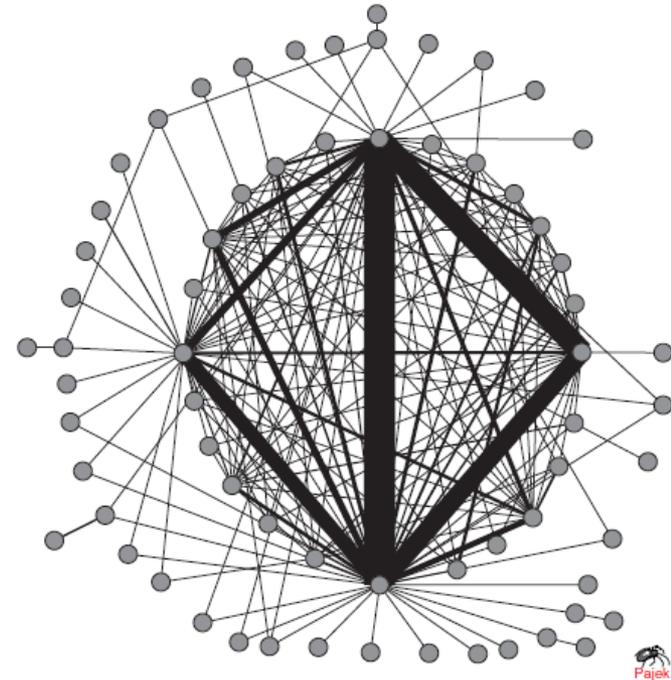


Image source : Soramäki, Bech, Arnold, Glass, and Beyeler (2007)

## Money funds -- seeking yields and seeking safety in 2011

Chernenko & Sunderam (2014) "Frictions in Shadow Banking"

Pre-downgrade (June)

Post-downgrade

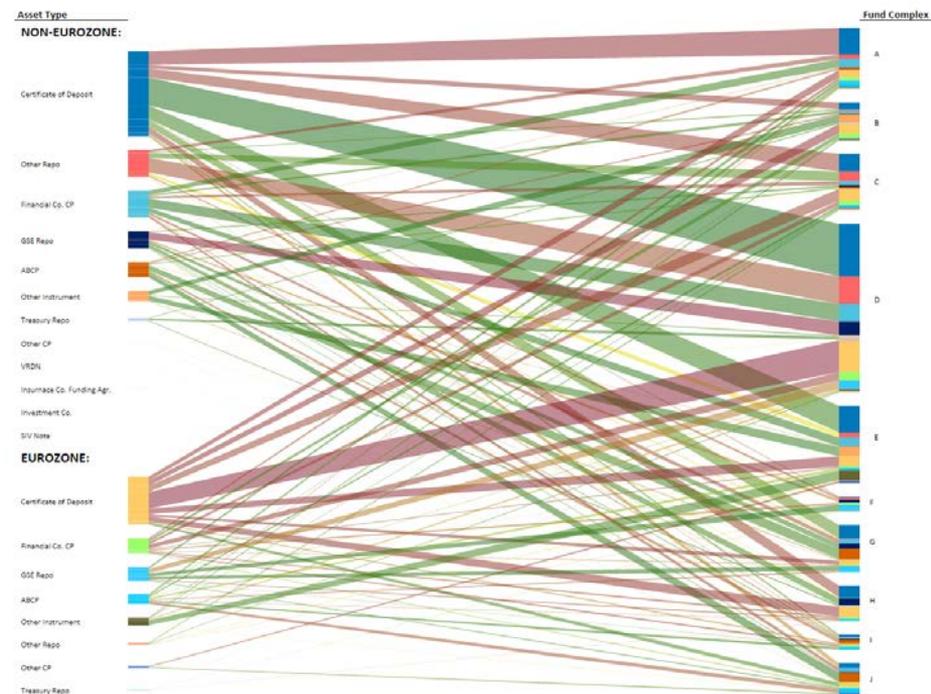
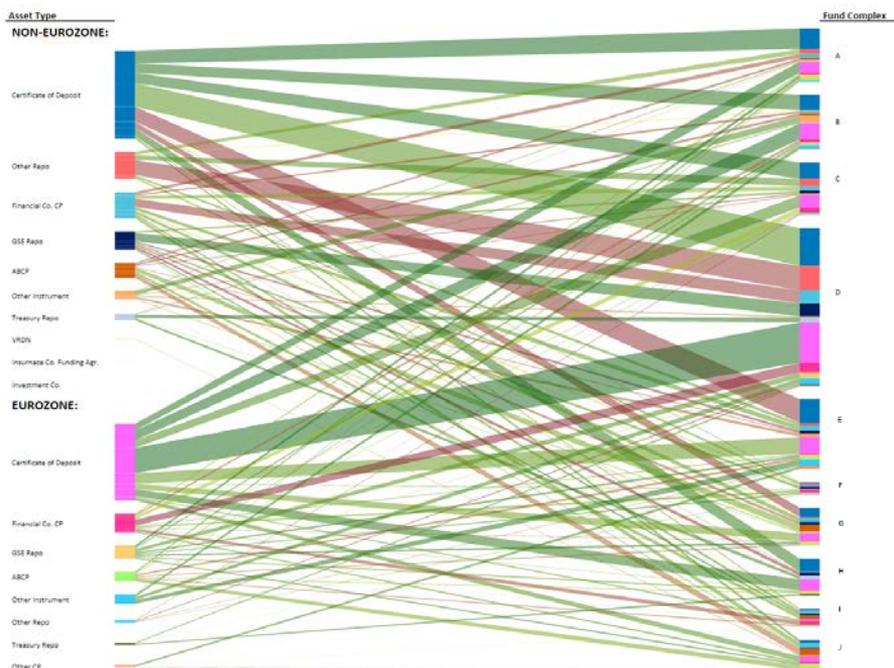


Image source : SEC N-MFP, OFIR analysis

## 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

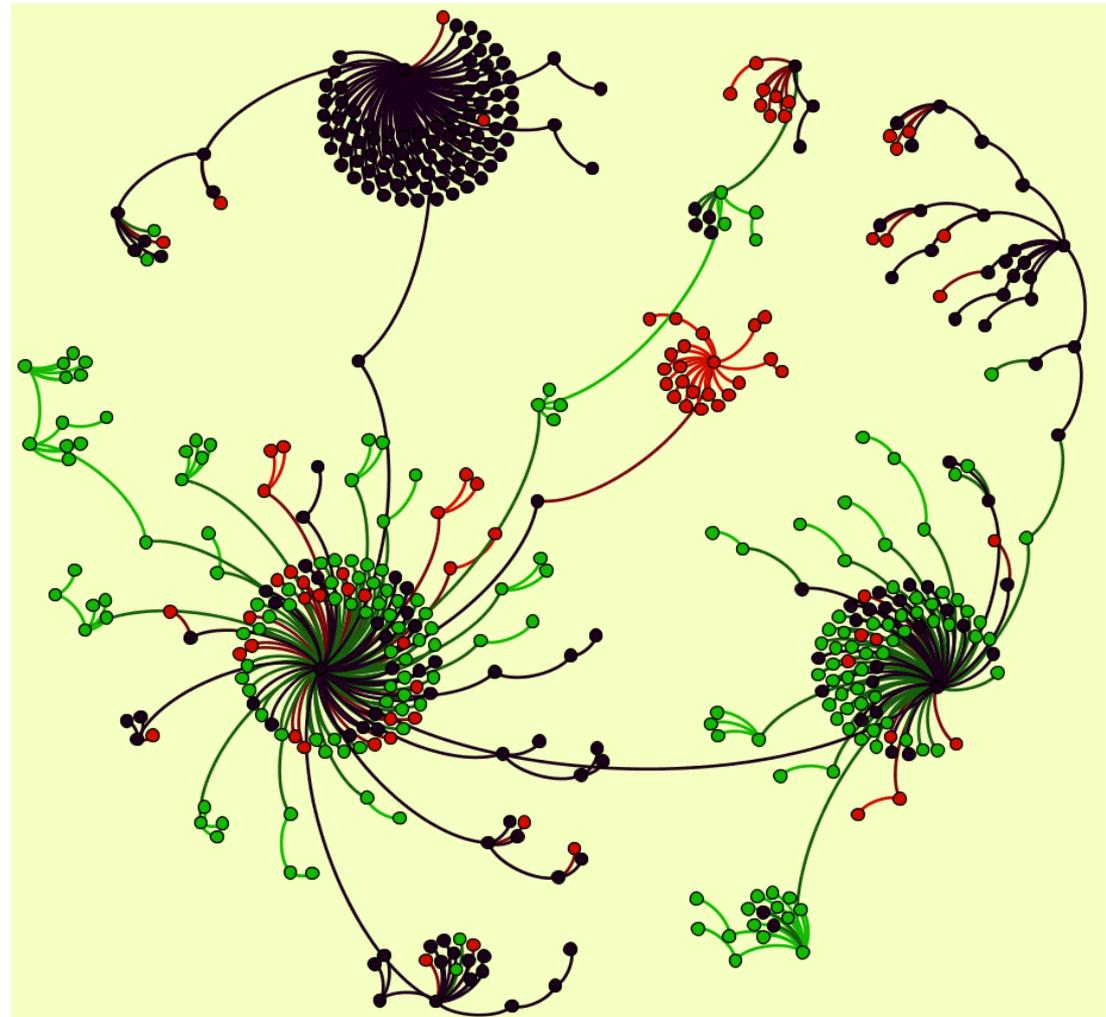
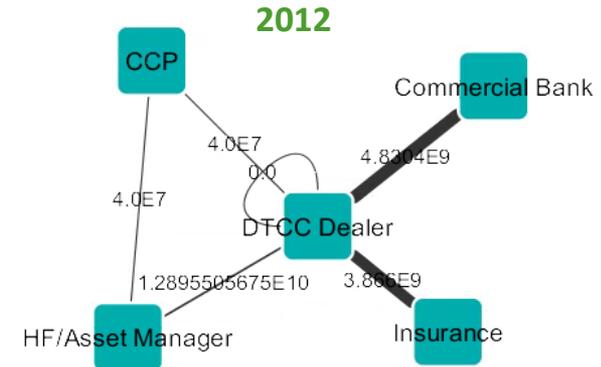
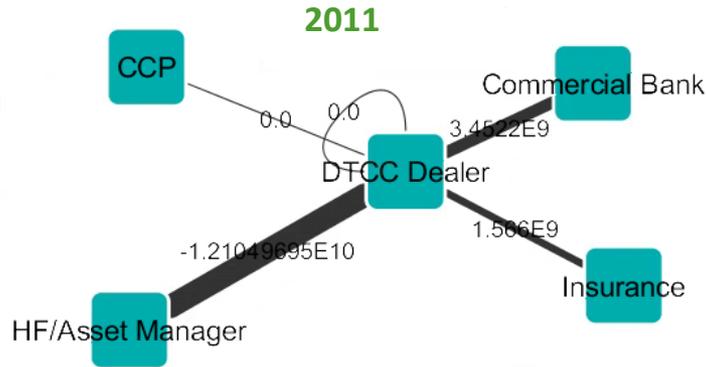


Image source : FFIEC (2015), OFR analysis

- Net positions



- Absolute value of positions

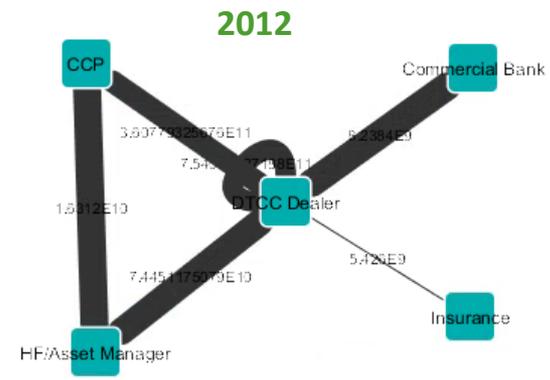
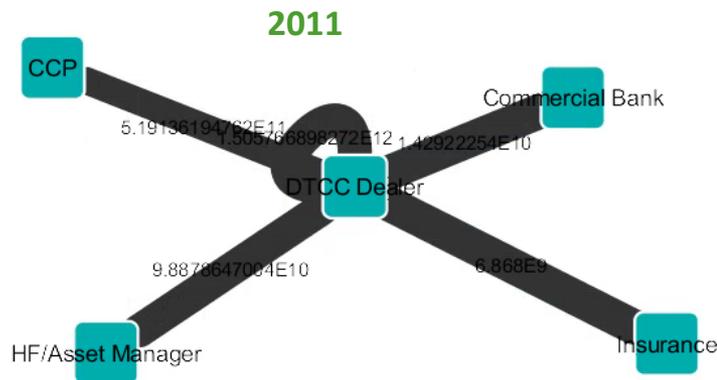


Image source : OFR analysis

# Net Positions in CDX.NA.IG.9



## Net positions aggregated by counterparty types

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

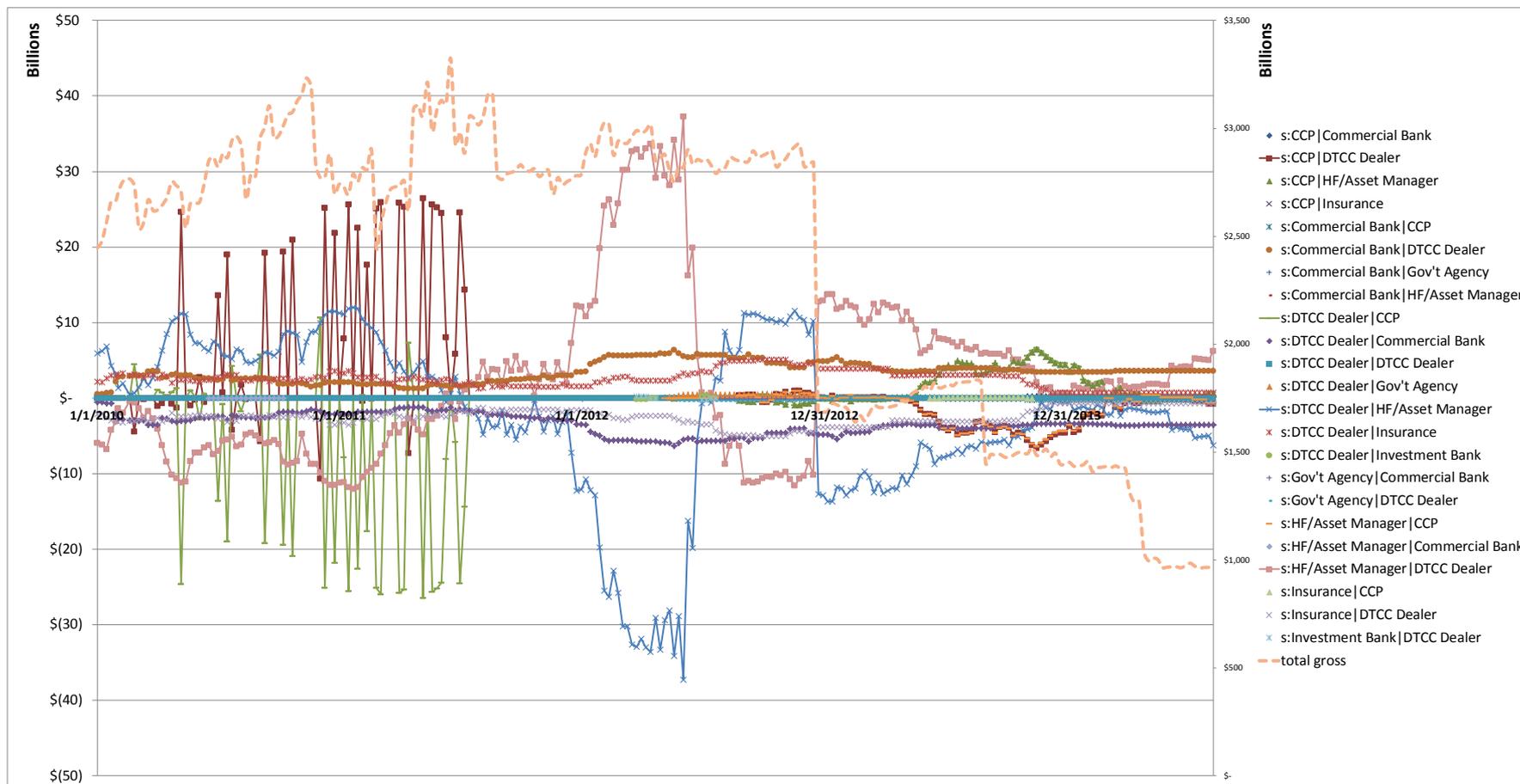


Image source : OFR analysis

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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

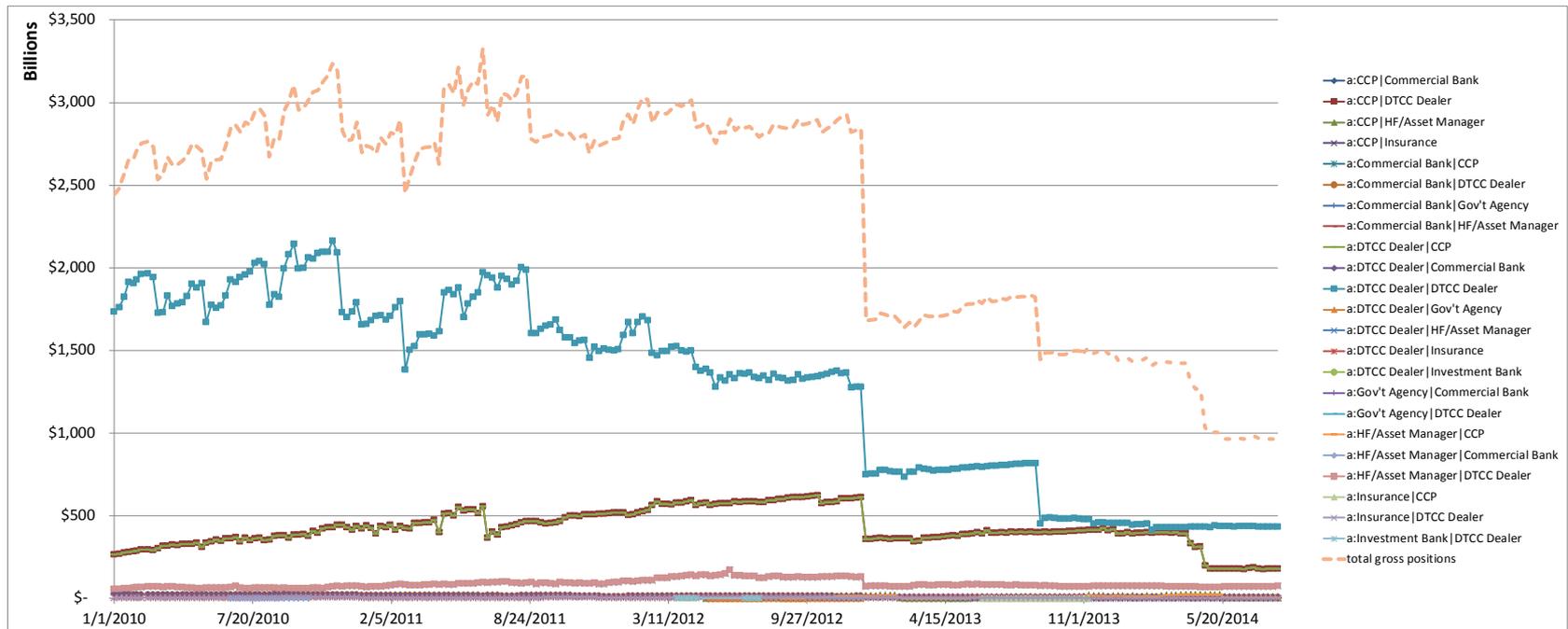


Image source : OFR analysis

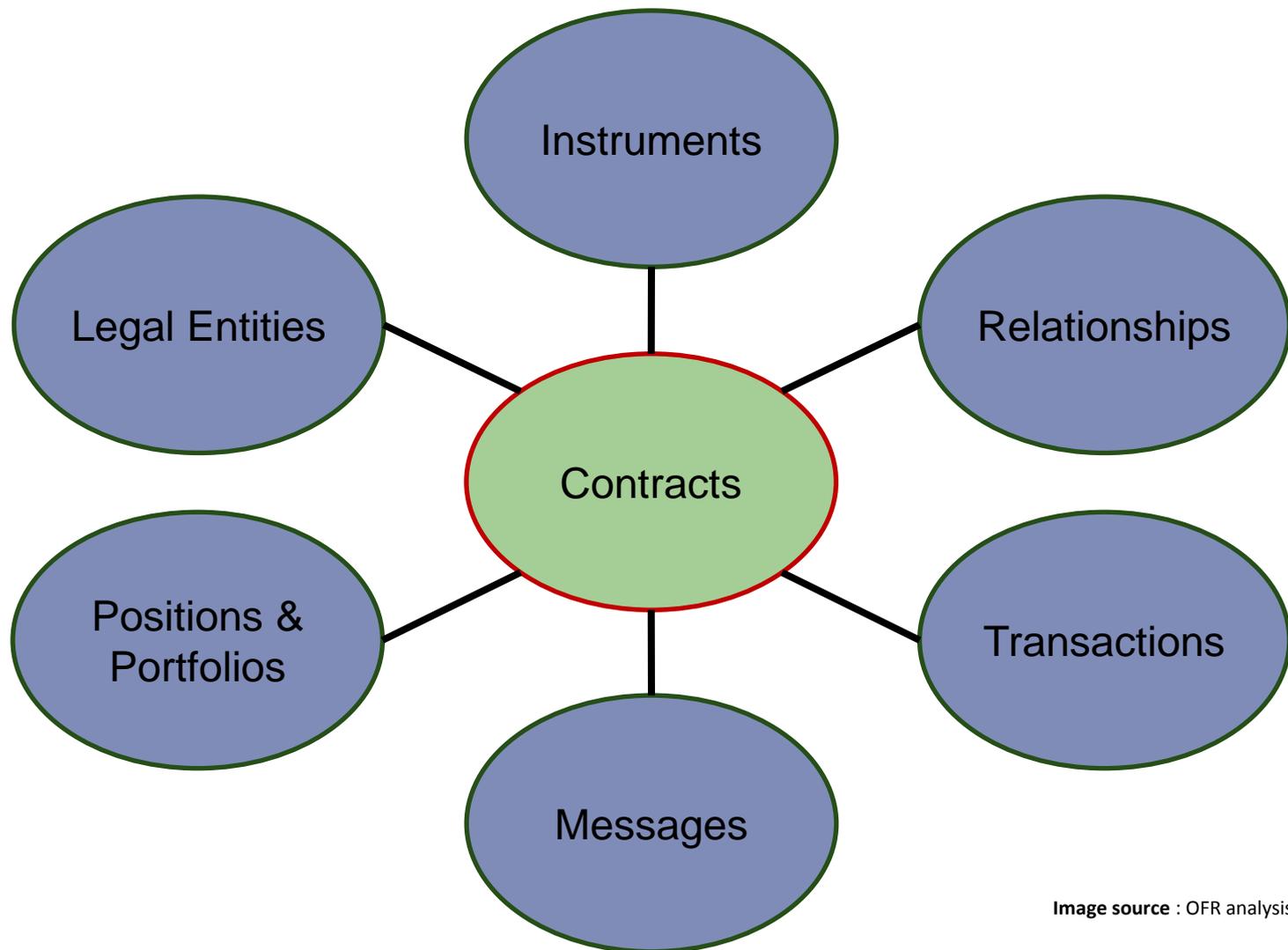


Image source : OFR analysis

# A “Toy” Loan Agreement



## 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

**Agreement**

This loan agreement dated June 1, 2014, by and between Lender Bank Co. ("Lender") and Borrower Corp. ("Borrower"), will set out the terms under which Lender will extend credit in the principal amount of \$1,000 to Borrower with an un-compounded interest rate of 5% per annum, included in the specified payment structure.

**1. The Loan:**  
At the request of Borrower, to be given on June 1, 2014, Lender will advance \$1000 to Borrower no later than June 2, 2014. If Borrower does not make such a request, this agreement will terminate.

**2. Repayment:**  
Subject to the other terms of this agreement, Borrower will repay the loan in the following payments:  
(a) Payment 1, due June 1, 2015, in the amount of \$550, representing a payment of \$500 as half of the principal and interest in the amount of \$50.  
(b) Payment 2, due June 1, 2016, in the amount of \$525, representing a payment of \$500 as the remaining half of the principal and interest in the amount of \$25.

**3. Representations and Warranties:**  
The Borrower represents and warrants, at the execution of this agreement, at the request for the advance of funds and at all times any repayment amount shall be outstanding, the Borrower's assets shall exceed liabilities, as determined under an application of the FIFO rule of accounting.

**4. Covenants:**  
The Borrower covenants that at the execution of this agreement, at the request for the advance of funds and at all times any repayment amount shall be outstanding, it will make timely payment of all debts and taxes as assessed and when due.

**5. Events of Default:**  
The Borrower will be in default under this agreement upon the occurrence of any of the following events or conditions, provided they shall remain uncured within a period of 30 days after notice is given to Borrower by Lender of their occurrence (such an uncured event is "Event of Default"):  
(a) Borrower shall fail to make timely payment of any amount due to Lender under;  
(b) Any of the representation or warranties of Borrower under the agreement shall prove untrue;  
(c) Borrower shall fail to perform any of its covenants under this agreement;  
(d) Borrower shall file for bankruptcy or insolvency under any applicable federal or state law.  
A default will be cured by the Borrower (i) remedying the potential event of default and (ii) giving effective notice of such remedy to the Lender.

**6. Acceleration on Default:**  
Upon the occurrence of an Event of Default all outstanding payments under this agreement will become immediately due and payable, including both principal and interest amounts, without further notice, prepayment, or demand to the Borrower.

**7. Choice of Law:**  
This agreement will be subject to the laws of the State of New York applicable to contracts entered into and performed wholly within interstate.

**8. Amendments and Waivers:**  
Any purported amendments, or waiver of rights under, this agreement will only be effective if set forth in writing and executed by both parties.

**9. Courts and Litigation:**  
Any legal action brought to enforce, interpret or otherwise deal with this agreement must be brought in the state courts of the State of New York located in New York County, and each of the parties agrees to the jurisdiction of such courts over both the parties themselves and over the subject matter of such a proceeding, and waives any claim that such a court may be an inconvenient forum.

**10. Time of the Essence; No Pre-Payment:**  
Timely performance is required for any action to be taken under this agreement, and, except as may otherwise be specifically provided herein, failure to take such action on the day specified will constitute a binding failure to take such action. Payments shall only be made on or after the date specified in Section 2 or on or after such other date as may be required under Section 6; no payments made on earlier dates shall not be accepted.

**11. Notices:**  
Notwithstanding for in this agreement will be given by an email to the email address set out below and will be effective upon receipt.  
[Lender email here]  
[Borrower email here]

Accepted and agreed:  
LENDER BANK CO. BORROWER CORP.  
By: \_\_\_\_\_ By: \_\_\_\_\_  
Title: \_\_\_\_\_ Title: \_\_\_\_\_

(NOTE: Statute of Limitations on debt obligations in NY is 6 years)  
Draft of July 23, 2014

- **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 ( $\Sigma$ )
  - 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  $Q$ ,  $\Sigma$  and  $\delta$ )
  - Graphical (depiction of states and transitions among them)
  - Regular expression (shorthand grammar of acceptable event sequences)

# Representation II: Tabular



State	Label	Natural Language Consequences and Correlates (A)	Sec
start <sup>0</sup>	Start	Contract is fully specified; key information (payment dates, notice addresses and procedures, choice of law and dispute process) delivered	7, 9, 11
q0 <sup>0</sup>	Active contract	Contract is fully signed/executed	
q1 <sup>0</sup>	Principal Requested	Borrower's has requested and awaits \$1,000	1
P1 <sup>0</sup>	Pmt 1 accruing		
P1d <sup>0</sup>	Pmt. 1 due		
P2 <sup>0</sup>	Pmt 2 accruing		
P2d <sup>0</sup>	Pmt. 2 due		
DI	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 <sup>1</sup>	Borr. notified of payment default	Borrower has 2 days to pay, or all payments accelerate	5
Nbnpd_1 <sup>1</sup>	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.) Covenant	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 <sup>1</sup>	Borr. notified of payment default	Borrower has 2 days to pay, or all payments accelerate	5
Nbnpd_2 <sup>1</sup>	Borr. notified of general default	Borrower has 2 days to pay, or all payments accelerate	5
xT <sup>1</sup>	TERM	Contract is fulfilled in accordance with its terms	
xL <sup>1</sup>	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 <sup>1</sup>	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

<sup>0</sup> States on the "happy" path of the contract lifecycle  
<sup>1</sup> Default states  
<sup>\*</sup> Terminal states

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

Initial State	Event	Resulting State
start <sup>0</sup>	A	q0
q0	B	xT
q0 <sup>0</sup>	C	q1
q1	B	DI
DI	D	xL
DI	E	xC
q1 <sup>0</sup>	F	P1
P1 <sup>0</sup>	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	Crisis2
Acc1	S	xT
Crisis1	E	xC
Crisis1	D	xL
Crisis1	S	xL
P1d <sup>0</sup>	Q	P2

Initial State	Event	Resulting State
P2 <sup>0</sup>	P	P2d
P2d	B	Db0_2
P2	H	Dbrw_2
P2	I	Dbcv_2
P2	J	Dbbkr_2
P2d <sup>0</sup>	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

<sup>0</sup> 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

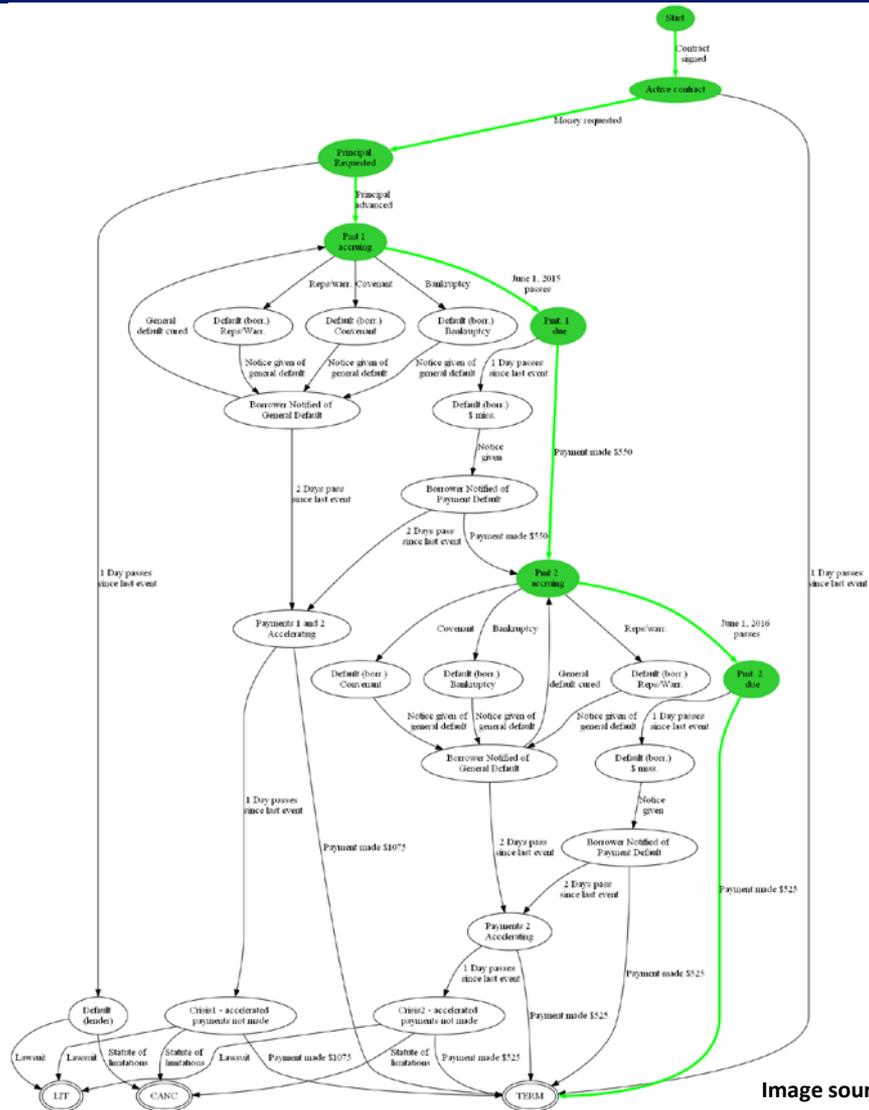


Image source: OFR analysis

## 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

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 descriptive 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

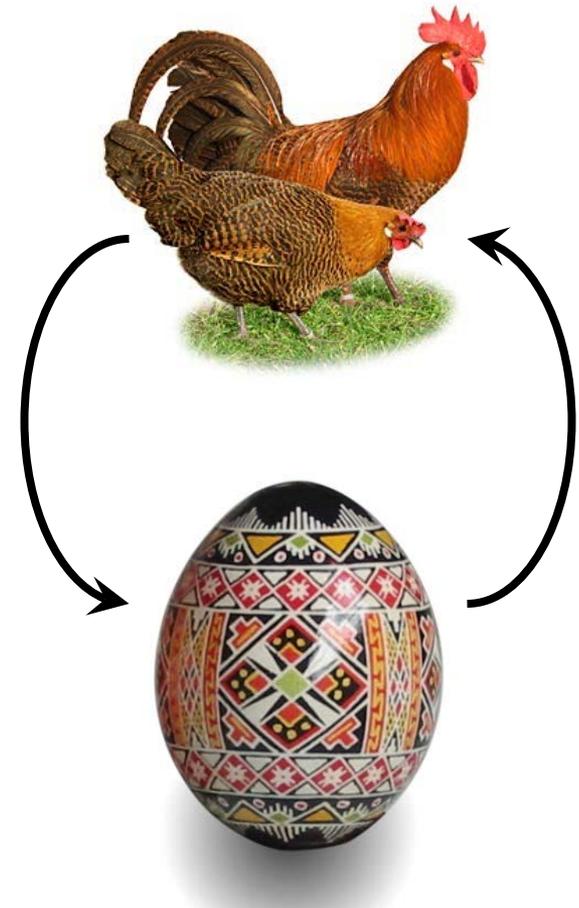


Image source : Stijn Ghesquiere (2004), [www.wikipedia.org](http://www.wikipedia.org)

## Endogenous Myopia

Firms will not disclose their positions

Myopia: firms' visibility distance  $\leq 1$

→ Role for public supervision

## State-dependent Data Requirements

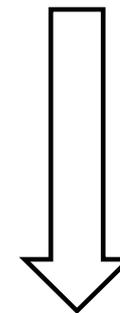
Supervisory needs increase under:

- 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!**