UNIVERSITY OF CALIFORNIA

Office of the Chief Investment Officer

An Agent-based Model for Financial Risk Dynamics

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Growing Portfolios Building Partnerships

UC Investments

Agent-based Models: The Traffic Engineer's Problem

Agents

Drivers have various heuristics -- speeders, lane-changers

Environment

They apply their heuristics based on the (visible) roadway and agents

Interaction

The agents act, the environment changes

It boils down to:

- Dynamics of interactions
- Driven by the heterogeneous agents in their environment
- With interactions that alter the environment

Why We Need This Sort of Approach

- We interact with our environment. We all mind our own business but end up in a stampede:
  Emergence

- We create and invent. The world is filled with surprises:
  Radical Uncertainty

- Our interactions create dynamic complexity that has no solution:
  Computational Irreducibility

- We change, and we change our world. The future will not look like the past:
  Non-ergodicity

Agent-based Models versus Standard Economics

Agent-based Models	Standard (Neoclassical) Model
Radical Uncertainty:	
Heuristics	Optimization
Emergence:	
Heterogeneous Agents	Representative Agent; Regularity
Computational Irreducibility:	
Open (Simulations)	Closed (Solvable; deductive)
Non-ergodicity:	
Interactive and changing world	Atomistic and Equilibrium World

Agent-based Models in Risk Management: The Fire Marshall's Problem

If there is a fire, how many will make it out?

- Egress
- Flammability
- Crowding

People do not walk out in a single file!

Agent-based Models in Risk Management: The Market Risk Manager's Problem

If there is a fire, how many will make it out?

- Egress
- Flammability
- Crowding

Egress	⇔	**Liquidity**
Flammability	⇔	**Leverage**
Crowding	⇔	**Concentration**

Market Dynamics: Leverage, Liquidity, Concentration

The Market Dynamic

Asset Shock or Funding Shock

→ Forced sales *due to leverage*

→ Price effects *due to concentration*

→Further declines *due to illiquidity*

⇒ Cascades and Contagion

Market Dynamics: Leverage, Liquidity, Concentration

The Market Dynamic

Asset Shock or Funding Shock

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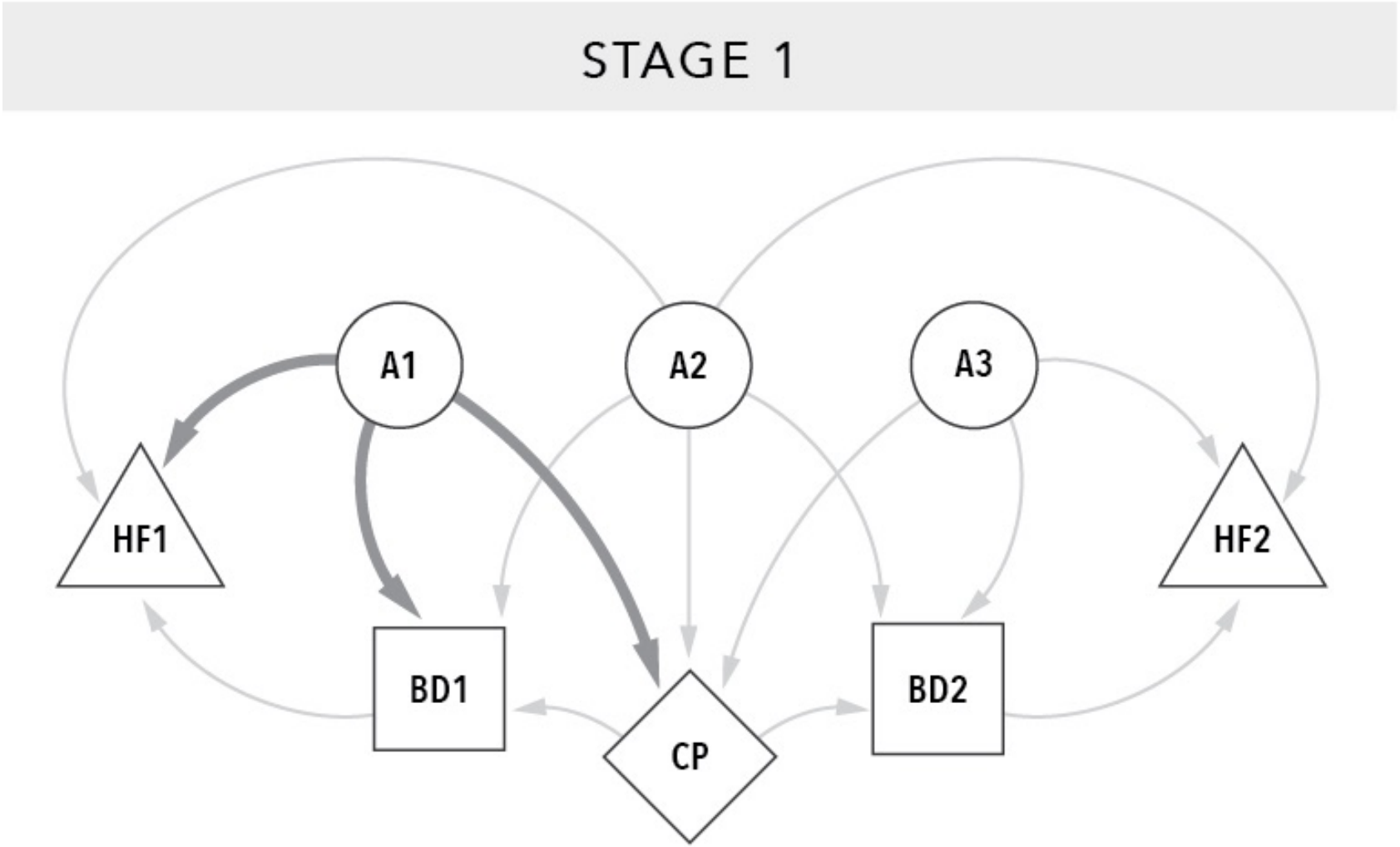
→ Price effects *due to concentration*

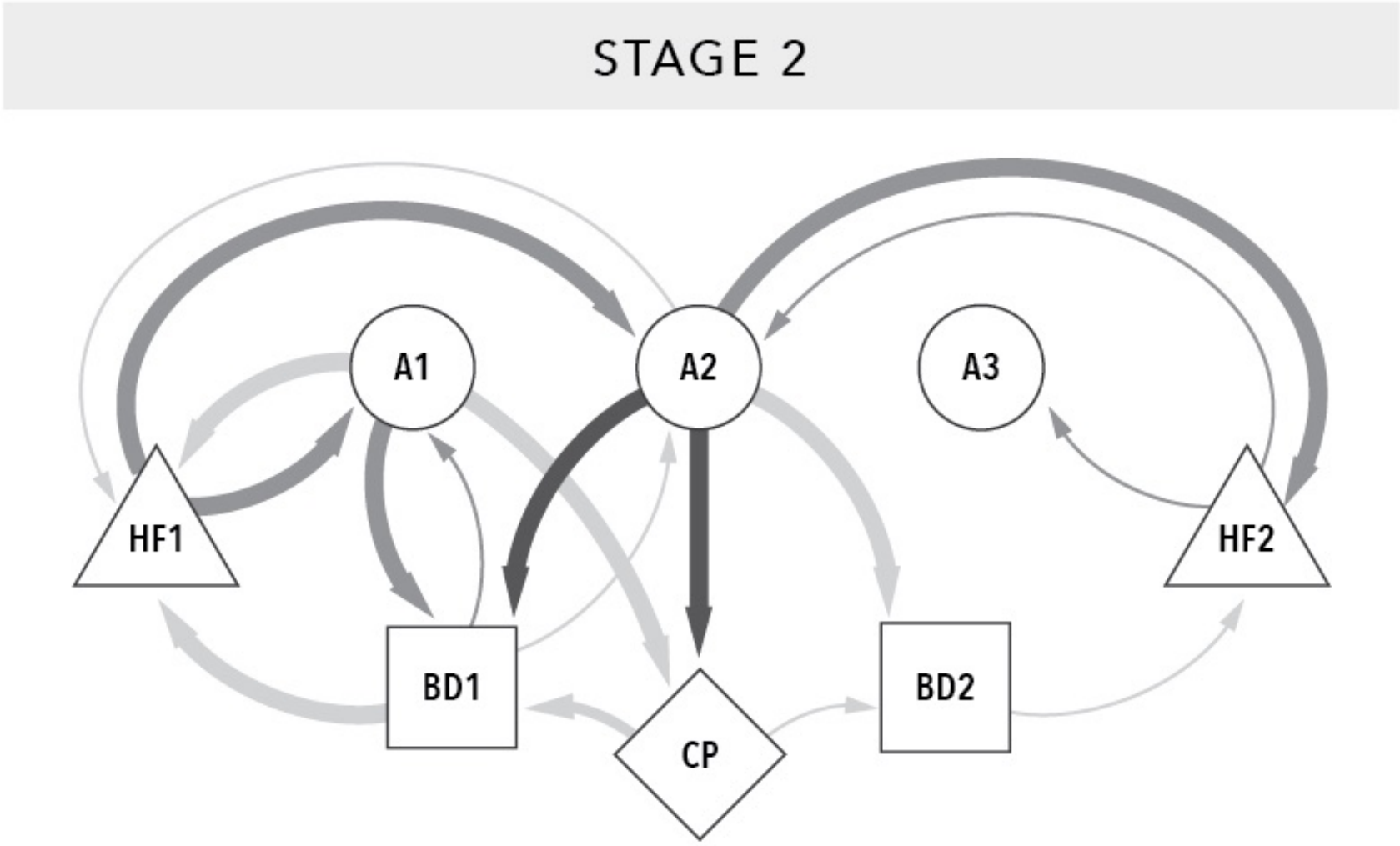
→Further declines *due to illiquidity*

⇒ Key Data: {leverage, concentration, illiquidity}

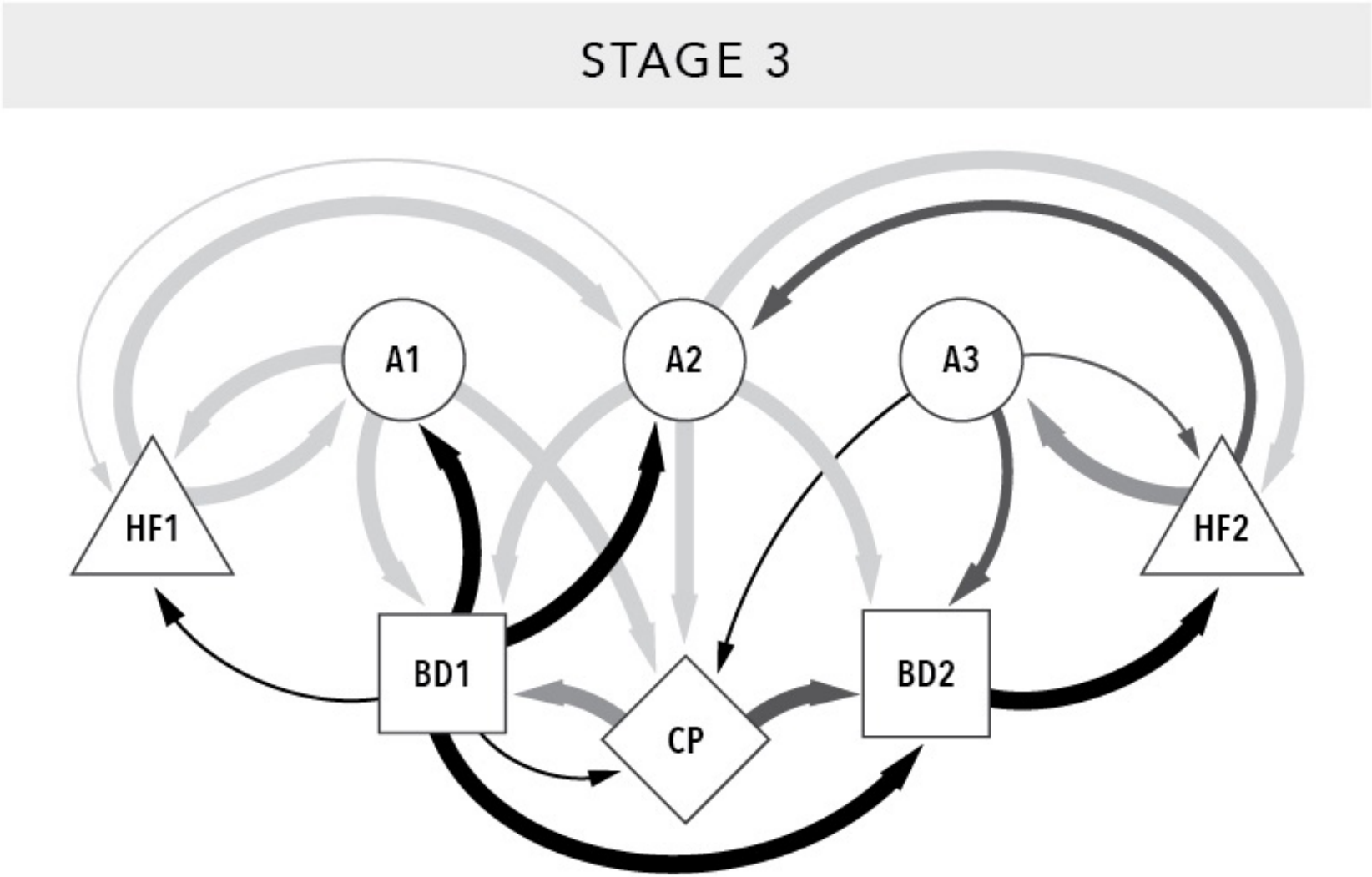
Market Dynamics Stage 1



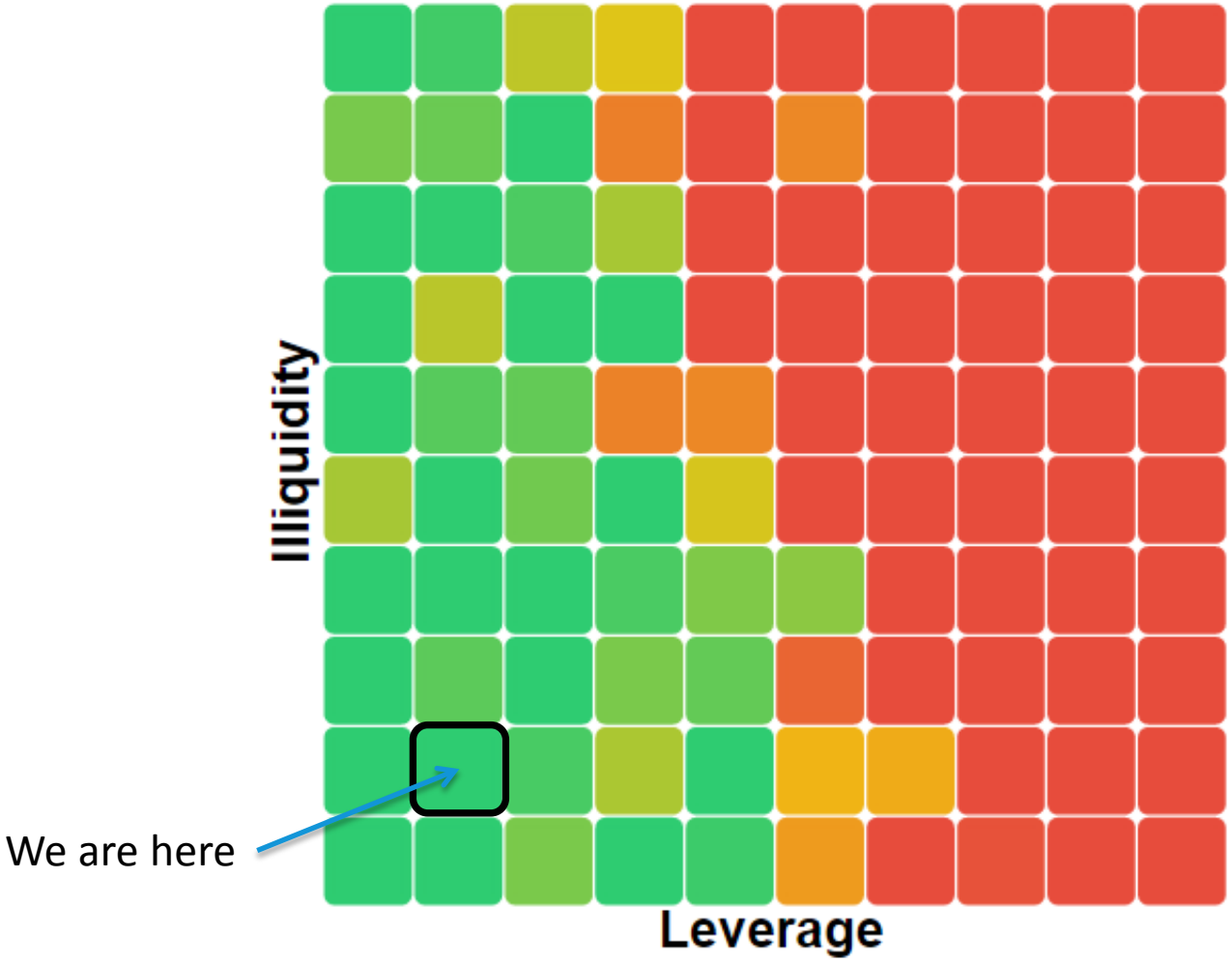
Market Dynamics Stage 2



Market Dynamics Stage 3

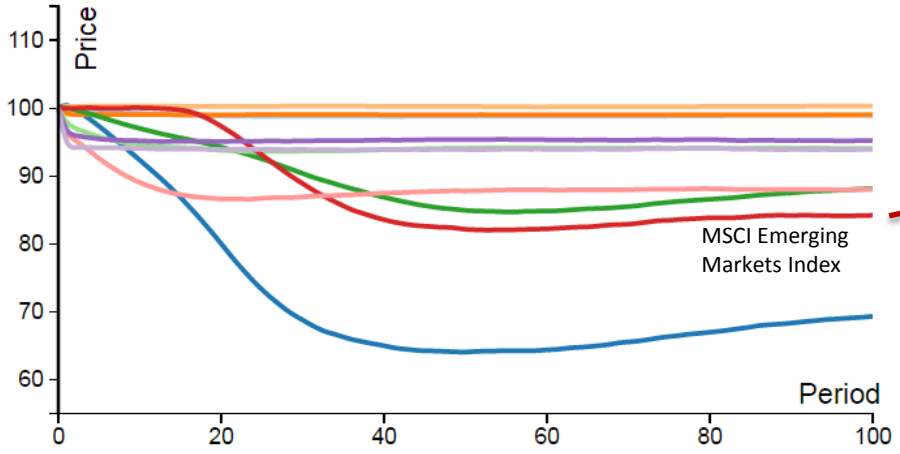


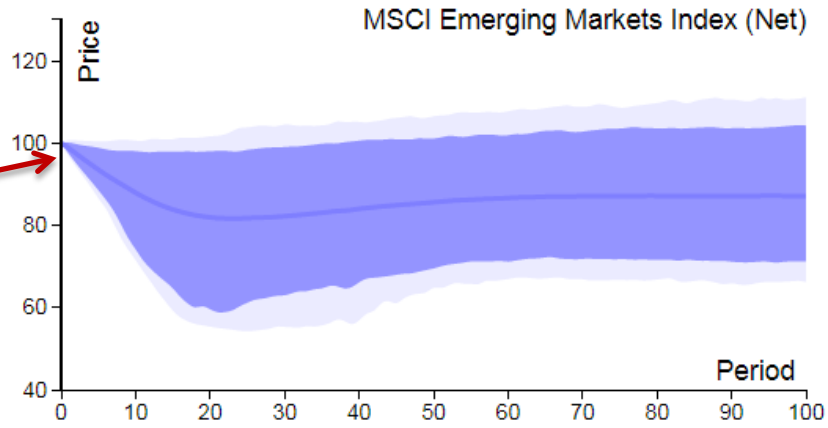
Heat Map for Risk



Risk within the Heat Map for Stress Scenario

Cascades and contagion evident here.





The Agent-based Model in Operation

Language

- Go – highly scalable and excellent at multithreading (thus parallel) processing.
- Javascript – for presentation, including D3.

Server

- Amazon Web Services (AWS) for our cloud infrastructure
- Master-worker architecture of Docker containers to parallelize simulations

Storage

- Results stored as *static* web sites on AWS's S3 storage solution

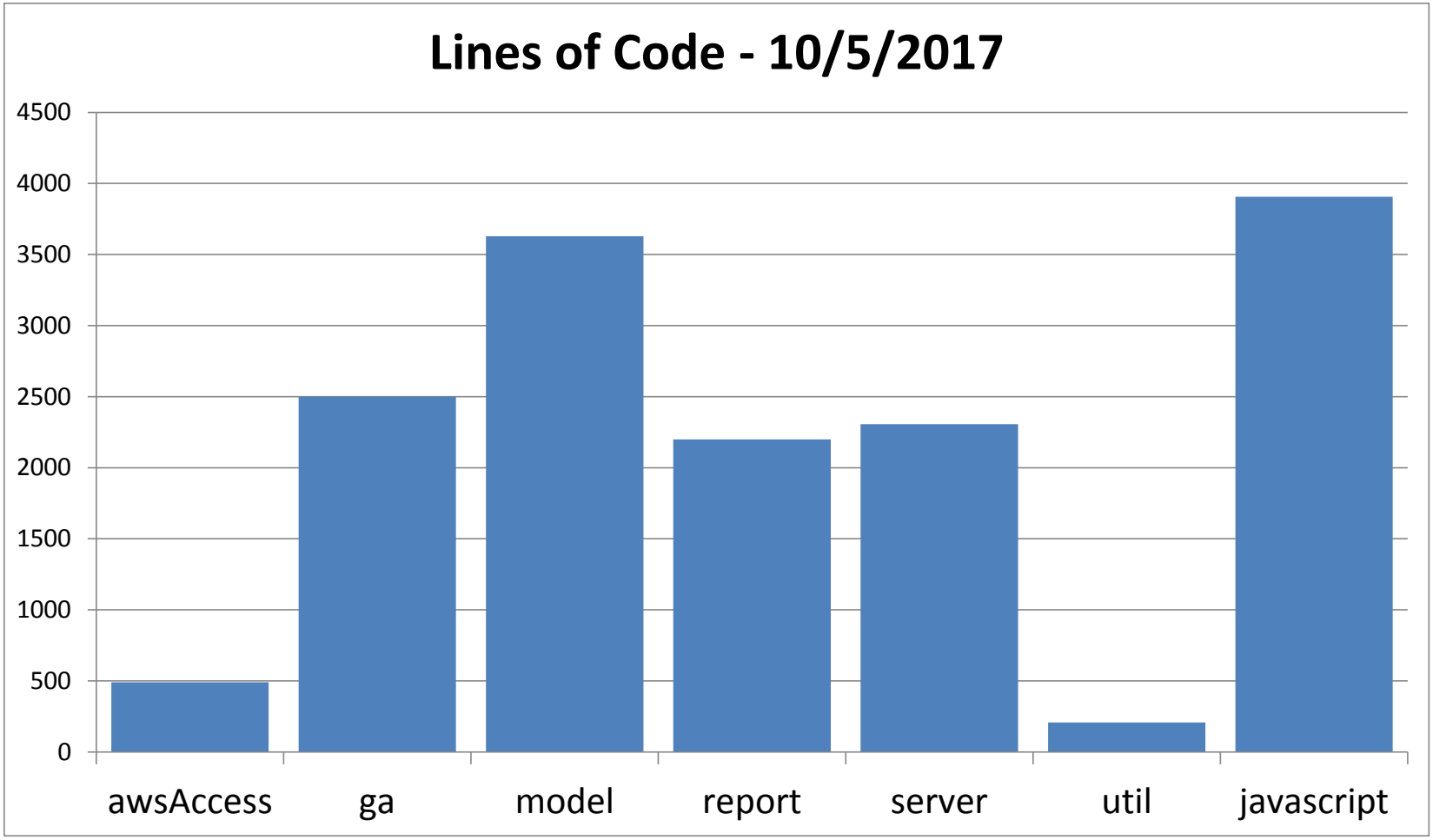
Operation

- Begin with Var/Covar of Risk 1.0
- Calibrate the Risk 3.0 model using a genetic algorithm
- Specify leverage / liquidity characteristics to generate a heat map
- Take any Risk 2.0 set of shocks and regenerate our heat map.

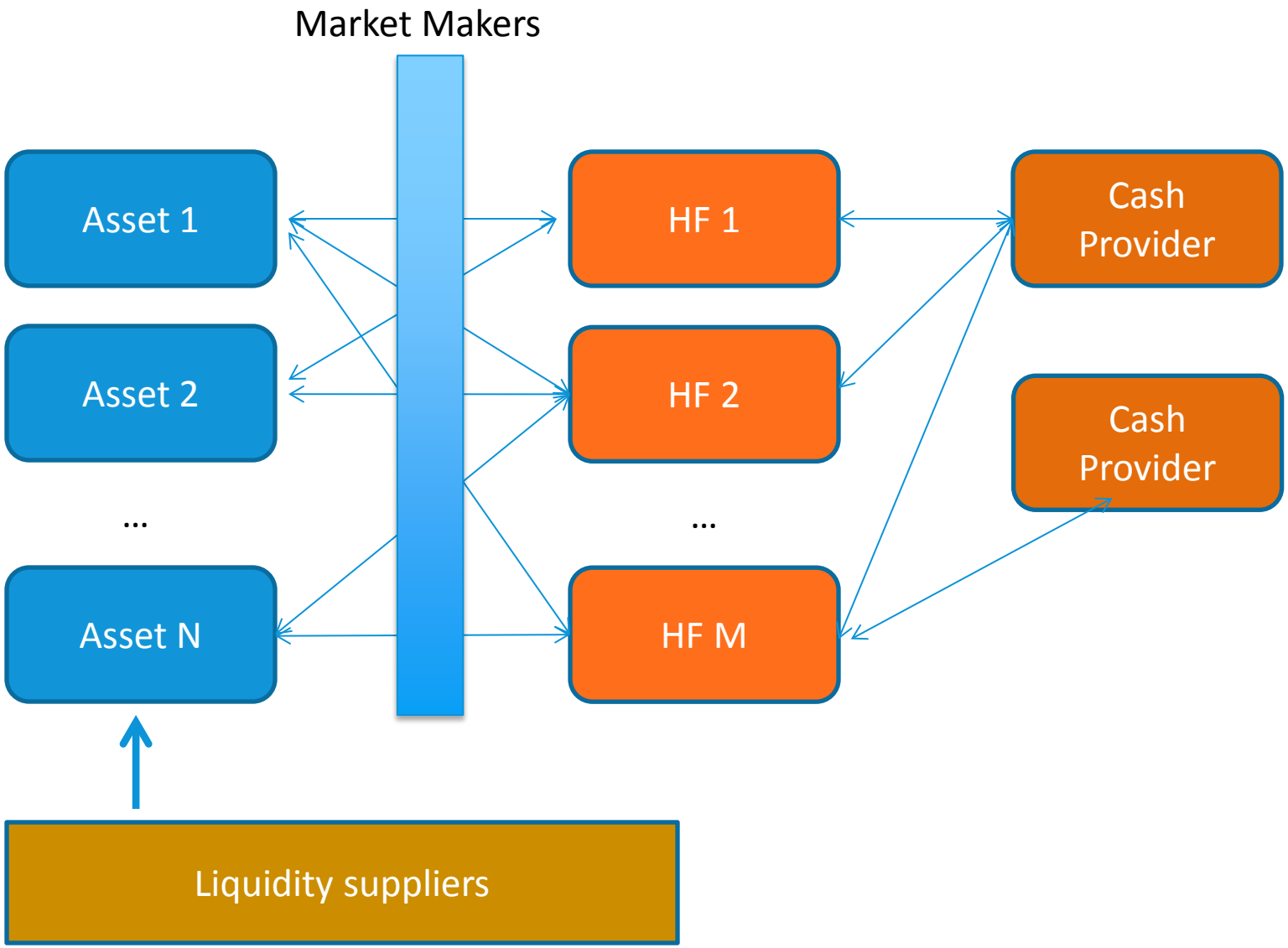
he Code – Go Packages

- **awsAccess** – encapsulates access to AWS services (S3 & SQS)
- **ga** – genetic algorithm optimization for model parameters
  - fitness – fitness functions for use with the genetic algorithm
- **model** – encapsulates the ABM
  - **agent** – all code related to *execution* of the model
  - **input** – takes model parameters via JSON or Excel file and creates model structures
    - **taxonomy** – describes our taxonomy of assets and contains code to import hedge fund holdings from Albourne
  - **output** – stores raw simulation results
- **report** – converts raw simulation results into a variety of reports
  - **tearsheet** – takes batch reports and creates product-level tear sheets for scenarios using an input Excel spreadsheet
- **server** – provides a web front-end for executing batches, viewing results and managing the distribution of batch execution across multiple servers
  - **gaControl** – manages the kick-off of a genetic algorithm run from a web request
  - **job** – handles job creation, report generation and other batch lifecycle events
  - **queue –** holds an event handler for “Manager” messages
  - **web** – wraps HTTP interface to server functionality
- **util** – utilities like random name generator, cholesky decomposition, etc.

How much code in each package?



Model Components



Agents

- Main agents are:
  - Hedge funds representing potential liquidity demanders
  - Cash providers
  - Market makers
  - Liquidity suppliers
  - Others can be added, or existing ones refined (i.e. for our volatility scenario)

- Agents have various heuristics.
  - Example: Hedge funds have target leverage and max leverage
    - Adjust their leverage to be near target leverage
    - Sell assets if their leverage is moving above the maximum allowable leverage (“forced selling”)

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Asset Prices

- Assets have a “fundamental price” and start at that price
- They can face exogenous shocks, which are part of a scenario
- In the no-shock, base case, they have geometric Brownian motion – generally drift is zero
- Prices are adjusted by the market makers’ inventory:
  - Forced selling increases inventory, decreases price
  - Liquidity suppliers decrease inventory, increase price

Shocks

- Shocks can be applied at any period
  - Generally, shocks are applied at period 1

- Shocks can be applied to assets and to cash providers' lending policies (i.e., changing maximum allowable leverage or maximum funding)

Inventory

Increases with forced selling by hedge funds

Decreases as liquidity suppliers come into the market. The liquidity supplier agent reduces inventory

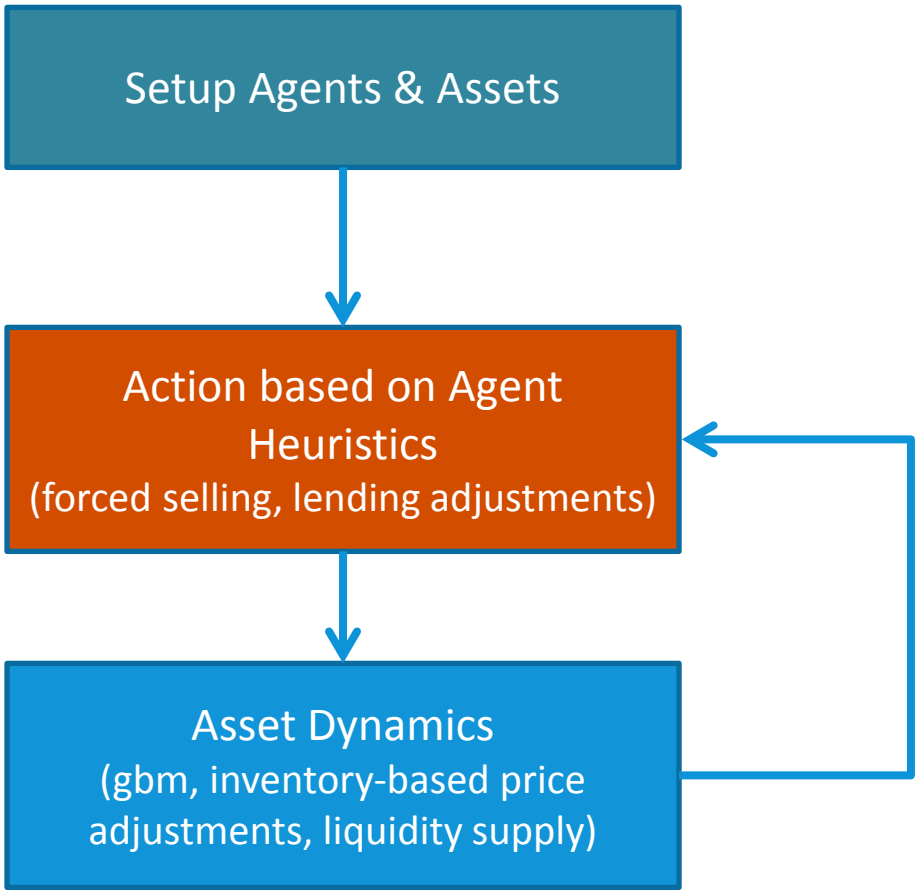
- Timing of agent follows a Poisson process. If there are, on average, many days between inventory checks, then the asset has lower liquidity.
- How much the agent buys is dependent upon inventory and how much the asset price has moved between checks (big moves mean smaller purchases)

Simulation Loop

func Generate()

Agent Execute() interface function

Within Run() function



Asset Calibration – Liquidity

- **Fund Percent** – percentage of daily volume represented by initial capital assigned to asset (via agents' asset allocation). Higher means less-liquid.
- **Inventory Percent** – percentage of daily volume held in inventory at beginning of simulation.
- **Liquidity of Market Makers** – Piece-wise linear. Inflection point when market maker capacity is gone. Based on market maker's capacity (via leverage) and inventory.
- **Liquidity Supply** -- Days between Supply: How often do liquidity suppliers come in to buy inventory? Higher means slower (less liquid)
- **Supply Scaling** – How much of outstanding inventory will be bought by liquidity suppliers over time.
  - We assume liquidity suppliers "visit" on a random basis.
  - If prices have dropped significantly, they will limit the amount of liquidity they will supply.

Agent Calibration – Hedge Funds

- **Initial Capital** – unlevered AUM of agent
- **Initial Leverage** - leverage of agent at beginning of simulation
- **Target Leverage** – leverage targeted by agent. A fund will adjust its borrowing gradually to hone in on target leverage.
- **Max Leverage** – the maximum leverage an agent can maintain before it is forced to sell assets to reduce leverage. In the case of forced selling, the agent still is targeting "target leverage" but the rate of convergence is higher.
- **Asset Allocation** – the target asset allocation of the fund. This is how concentration/co-concentration are specified.

Agent Calibration

Agents

Name	Type	Cash Provider	Initial Capital	Initial Leverage	Target Leverage	Max Leverage	Asset Alloc
Fund 1	HF	CP 1	7,904,707,408	5.87	4.5	8	edit
Fund 2	HF	CP 1	3,501,071,942	7.14	4.5	8	edit
Fund 3	HF	CP 1	10,521,782,254	2.48	4.5	8	edit
Fund 4	HF	CP 2	5,117,436,955	5.75	4.5	8	edit
Fund 5	HF	CP 2	12,627,527,276	2.18	4.5	8	edit
Fund 6	HF	CP 2	6,075,761,044	7.21	4.5	8	edit
Fund 7	HF	CP 2	5,148,928,054	6.83	4.5	8	edit
Fund 8	HF	CP 2	10,000,000,000	4.28	4.5	8	edit
Fund 9	HF	CP 2	10,000,000,000	1.95	4.5	8	edit
Fund 10	HF	CP 2	14,700,556,942	7.36	4.5	8	edit
Fund 11	HF	CP 2	10,000,000,000	5.21	4.5	8	edit
Fund 12	HF	CP 2	10,300,831,617	4.13	4.5	8	edit
Fund 13	HF	CP 2	7,485,906,830	6.73	4.5	8	edit
Fund 14	HF	CP 2	5,775,768,673	7.7	4.5	8	edit
Fund 15	HF	CP 2	7,628,947,258	7.7	4.5	8	edit
UCRP	AM	CP 1	100	1	1	1	edit
UCRP FI	AM	CP 1	100	1	1	1	edit
UCRP EQ	AM	CP 1	100	1	1	1	edit
GEP	AM	CP 1	100	1	1	1	edit
GEP FI	AM	CP 1	100	1	1	1	edit
GEP EQ	AM	CP 1	100	1	1	1	edit
TRIP	AM	CP 1	100	1	1	1	edit
TRIP FI	AM	CP 1	100	1	1	1	edit
TRIP EQ	AM	CP 1	100	1	1	1	edit
CP 1	CP		10,000,000,000	3.75	3.75	5	edit
CP 2	CP		10,000,000,000	3.75	3.75	5	edit

Agent Calibration Parameters – Asset Allocation

Asset Allocation

	BBG Barc Securitized Index	BBG Barc U.S. Credit Index	BBG Barc Government Index	BBG Barc U.S. Aggregate Index	BBG Barc US TIPS Index Series L	BofA ML High Yield Cash Pay Index (JOA…	JP Morgan EMBI Global Diversified Index	MSCI Emerging Markets Index (Net)	MSCI All Country World ex US - Net Retu…	MSCI ACWI IMI with USA Net Index	Russell 3000 Index	USD
Fund 5						37%	63%					
UCRP FI				62%	13%	15%	11%					
Fund 3	8%	8%		67%		8%	8%					
Fund 9	5%	56%		5%		29%	5%					
Fund 2	5%	5%	12%	5%	35%	33%	5%					
Fund 1	22%	23%	4%	13%	26%	7%	4%					
GEP FI			34%		22%	30%	14%					
Fund 14		68%		9%		12%					11%	
UCRP				17%	4%	4%	3%	5%	5%	46%	17%	
Fund 8	2%	2%	9%	23%	5%	2%	2%	19%	9%	2%	8%	18%
Fund 6	1%	11%	8%	10%	1%	15%	5%	10%	14%	11%	1%	14%
Fund 15								62%	5%	5%	24%	5%
GEP			6%		4%	6%	3%	11%	10%	48%	11%	
Fund 7						9%	32%	59%				
Fund 12							50%	50%				
GEP EQ								14%	13%	59%	14%	
Fund 11								7%	7%	7%	78%	
UCRP EQ								7%	7%	64%	23%	
Fund 10						22%		18%	3%	21%	35%	
Fund 13								50%	50%			
Fund 4	39%	6%				55%						
TRIP	15%	24%	15%							46%		
TRIP FI	28%	45%	27%									
TRIP EQ										100%		
CP 1		100%										
CP 2		100%										