



# Category Theory for Semantic Data Interoperability

Exchange and Consolidate Data for Agile PLM at Scale



# Data Integration Challenges

<>requirement>> Climb: One-engine-inoperative	Requirement
FEDERAL AVIATION ADMINISTRATION (FAA) Title 14, Chapter 1, Subchapter C 25.121  ...(a) Takeoff; landing gear extended... the steady gradient of column... not less than 0.5 percent... for four-engine airplanes	

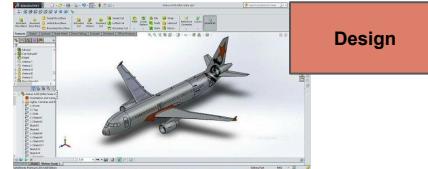
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Test Case	<<testcase>> Climb: One-engine-inoperative
	Perform simulation under conditions...

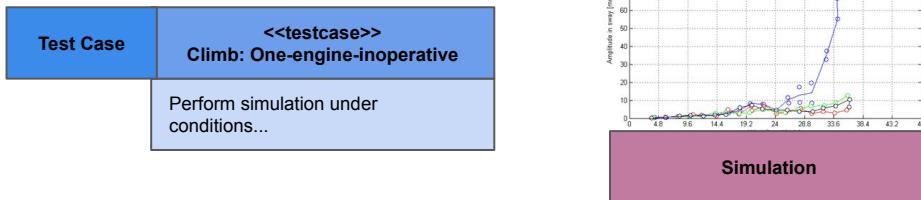
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<p>FEDERAL AVIATION ADMINISTRATION (FAA) Title 14, Chapter 1, Subchapter C 25.121</p> <p>...(a) Takeoff; landing gear extended... the steady gradient of column... not less than 0.5 percent... for four-engine airplanes</p>	



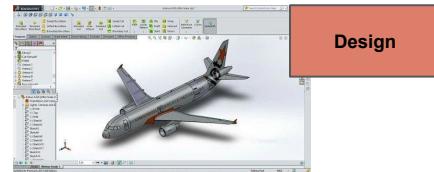
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# Data Integration Challenges



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Design

Manufacturing Process Planning												
ID	Part	Op	Eq	Op								
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231	231	1	Y	2	Y							

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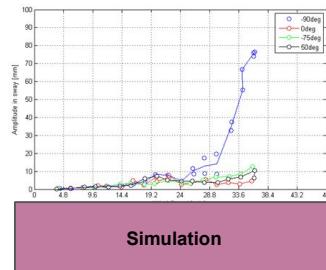
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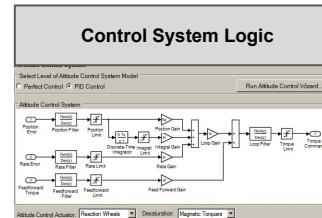
Design



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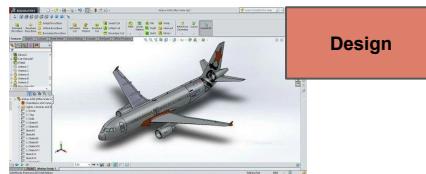


Simulation



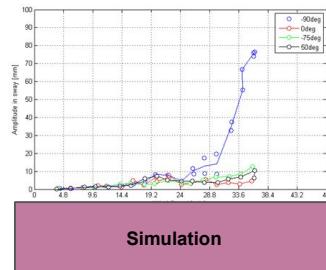
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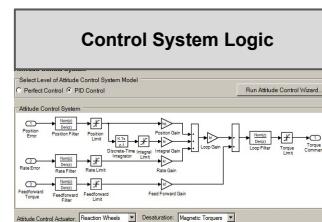


Design

Test Case	<<testcase>> <b>Climb: One-engine-inoperative</b>
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## Simulation

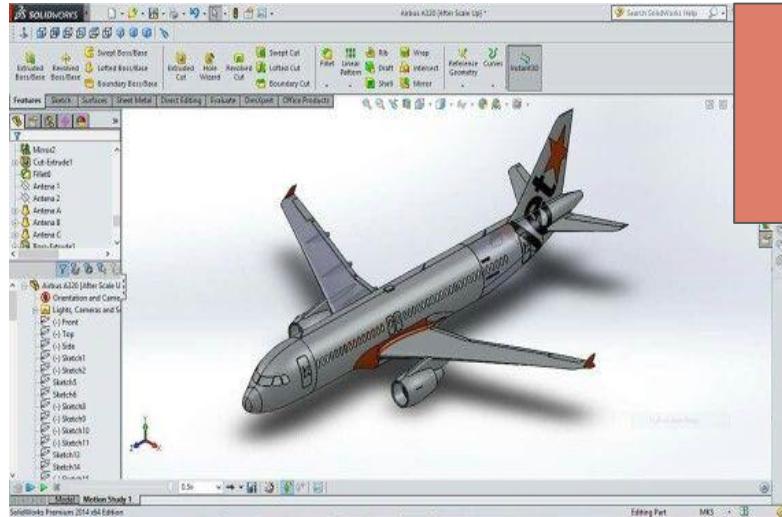


Job ID	Job Name	Start Date	End Date	Status	Machine Allocation		Overall Status	Last Update
					Machine 1	Machine 2		
J001	Job 001	2023-01-01	2023-01-05	In Progress	Machine A	Machine B	On Track	2023-01-03 10:00
J002	Job 002	2023-01-02	2023-01-06	Pending	Machine C	Machine D	At Risk	2023-01-04 14:00
J003	Job 003	2023-01-03	2023-01-07	Completed	Machine E	Machine F	On Track	2023-01-06 16:00
J004	Job 004	2023-01-04	2023-01-08	In Progress	Machine G	Machine H	At Risk	2023-01-05 12:00
J005	Job 005	2023-01-05	2023-01-09	Pending	Machine I	Machine J	At Risk	2023-01-06 09:00
J006	Job 006	2023-01-06	2023-01-10	Completed	Machine K	Machine L	On Track	2023-01-09 18:00
J007	Job 007	2023-01-07	2023-01-11	In Progress	Machine M	Machine N	At Risk	2023-01-08 15:00
J008	Job 008	2023-01-08	2023-01-12	Pending	Machine O	Machine P	At Risk	2023-01-09 10:00
J009	Job 009	2023-01-09	2023-01-13	Completed	Machine Q	Machine R	On Track	2023-01-12 14:00
J010	Job 010	2023-01-10	2023-01-14	In Progress	Machine S	Machine T	At Risk	2023-01-11 11:00
J011	Job 011	2023-01-11	2023-01-15	Pending	Machine U	Machine V	At Risk	2023-01-12 08:00
J012	Job 012	2023-01-12	2023-01-16	Completed	Machine W	Machine X	On Track	2023-01-15 19:00
J013	Job 013	2023-01-13	2023-01-17	In Progress	Machine Y	Machine Z	At Risk	2023-01-14 13:00
J014	Job 014	2023-01-14	2023-01-18	Pending	Machine AA	Machine BB	At Risk	2023-01-15 09:00
J015	Job 015	2023-01-15	2023-01-19	Completed	Machine CC	Machine DD	On Track	2023-01-18 17:00
J016	Job 016	2023-01-16	2023-01-20	In Progress	Machine EE	Machine FF	At Risk	2023-01-17 10:00
J017	Job 017	2023-01-17	2023-01-21	Pending	Machine GG	Machine HH	At Risk	2023-01-18 07:00
J018	Job 018	2023-01-18	2023-01-22	Completed	Machine II	Machine JJ	On Track	2023-01-21 16:00
J019	Job 019	2023-01-19	2023-01-23	In Progress	Machine KK	Machine LL	At Risk	2023-01-20 12:00
J020	Job 020	2023-01-20	2023-01-24	Pending	Machine MM	Machine NN	At Risk	2023-01-21 09:00
J021	Job 021	2023-01-21	2023-01-25	Completed	Machine OO	Machine PP	On Track	2023-01-24 14:00
J022	Job 022	2023-01-22	2023-01-26	In Progress	Machine QQ	Machine RR	At Risk	2023-01-23 11:00
J023	Job 023	2023-01-23	2023-01-27	Pending	Machine TT	Machine YY	At Risk	2023-01-24 08:00
J024	Job 024	2023-01-24	2023-01-28	Completed	Machine ZZ	Machine AA	On Track	2023-01-27 18:00
J025	Job 025	2023-01-25	2023-01-29	In Progress	Machine BB	Machine CC	At Risk	2023-01-26 13:00
J026	Job 026	2023-01-26	2023-01-30	Pending	Machine DD	Machine EE	At Risk	2023-01-27 09:00
J027	Job 027	2023-01-27	2023-01-31	Completed	Machine GG	Machine HH	On Track	2023-01-30 16:00
J028	Job 028	2023-01-28	2023-01-32	In Progress	Machine KK	Machine LL	At Risk	2023-01-29 12:00
J029	Job 029	2023-01-29	2023-01-33	Pending	Machine MM	Machine NN	At Risk	2023-01-30 09:00
J030	Job 030	2023-01-30	2023-01-34	Completed	Machine OO	Machine PP	On Track	2023-01-33 14:00
J031	Job 031	2023-01-31	2023-01-35	In Progress	Machine QQ	Machine RR	At Risk	2023-01-32 11:00
J032	Job 032	2023-01-32	2023-01-36	Pending	Machine TT	Machine YY	At Risk	2023-01-33 08:00
J033	Job 033	2023-01-33	2023-01-37	Completed	Machine ZZ	Machine AA	On Track	2023-01-36 18:00
J034	Job 034	2023-01-34	2023-01-38	In Progress	Machine BB	Machine CC	At Risk	2023-01-35 13:00
J035	Job 035	2023-01-35	2023-01-39	Pending	Machine DD	Machine EE	At Risk	2023-01-36 09:00
J036	Job 036	2023-01-36	2023-01-40	Completed	Machine GG	Machine HH	On Track	2023-01-39 16:00
J037	Job 037	2023-01-37	2023-01-41	In Progress	Machine KK	Machine LL	At Risk	2023-01-38 12:00
J038	Job 038	2023-01-38	2023-01-42	Pending	Machine MM	Machine NN	At Risk	2023-01-39 09:00
J039	Job 039	2023-01-39	2023-01-43	Completed	Machine OO	Machine PP	On Track	2023-01-42 14:00
J040	Job 040	2023-01-40	2023-01-44	In Progress	Machine QQ	Machine RR	At Risk	2023-01-41 11:00
J041	Job 041	2023-01-41	2023-01-45	Pending	Machine TT	Machine YY	At Risk	2023-01-42 08:00
J042	Job 042	2023-01-42	2023-01-46	Completed	Machine ZZ	Machine AA	On Track	2023-01-45 18:00
J043	Job 043	2023-01-43	2023-01-47	In Progress	Machine BB	Machine CC	At Risk	2023-01-44 13:00
J044	Job 044	2023-01-44	2023-01-48	Pending	Machine DD	Machine EE	At Risk	2023-01-45 09:00
J045	Job 045	2023-01-45	2023-01-49	Completed	Machine GG	Machine HH	On Track	2023-01-48 16:00
J046	Job 046	2023-01-46	2023-01-50	In Progress	Machine KK	Machine LL	At Risk	2023-01-47 12:00
J047	Job 047	2023-01-47	2023-01-51	Pending	Machine MM	Machine NN	At Risk	2023-01-48 09:00
J048	Job 048	2023-01-48	2023-01-52	Completed	Machine OO	Machine PP	On Track	2023-01-51 14:00
J049	Job 049	2023-01-49	2023-01-53	In Progress	Machine QQ	Machine RR	At Risk	2023-01-50 11:00
J050	Job 050	2023-01-50	2023-01-54	Pending	Machine TT	Machine YY	At Risk	2023-01-51 08:00
J051	Job 051	2023-01-51	2023-01-55	Completed	Machine ZZ	Machine AA	On Track	2023-01-54 18:00
J052	Job 052	2023-01-52	2023-01-56	In Progress	Machine BB	Machine CC	At Risk	2023-01-53 13:00
J053	Job 053	2023-01-53	2023-01-57	Pending	Machine DD	Machine EE	At Risk	2023-01-54 09:00
J054	Job 054	2023-01-54	2023-01-58	Completed	Machine GG	Machine HH	On Track	2023-01-57 16:00
J055	Job 055	2023-01-55	2023-01-59	In Progress	Machine KK	Machine LL	At Risk	2023-01-56 12:00
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J058	Job 058	2023-01-58	2023-01-62	In Progress	Machine QQ	Machine RR	At Risk	2023-01-59 11:00
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J060	Job 060	2023-01-60	2023-01-64	Completed	Machine ZZ	Machine AA	On Track	2023-01-63 18:00
J061	Job 061	2023-01-61	2023-01-65	In Progress	Machine BB	Machine CC	At Risk	2023-01-62 13:00
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J064	Job 064	2023-01-64	2023-01-68	In Progress	Machine KK	Machine LL	At Risk	2023-01-65 12:00
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J066	Job 066	2023-01-66	2023-01-70	Completed	Machine OO	Machine PP	On Track	2023-01-69 14:00
J067	Job 067	2023-01-67	2023-01-71	In Progress	Machine QQ	Machine RR	At Risk	2023-01-68 11:00
J068	Job 068	2023-01-68	2023-01-72	Pending	Machine TT	Machine YY	At Risk	2023-01-69 08:00
J069	Job 069	2023-01-69	2023-01-73	Completed	Machine ZZ	Machine AA	On Track	2023-01-72 18:00
J070	Job 070	2023-01-70	2023-01-74	In Progress	Machine BB	Machine CC	At Risk	2023-01-71 13:00
J071	Job 071	2023-01-71	2023-01-75	Pending	Machine DD	Machine EE	At Risk	2023-01-72 09:00
J072	Job 072	2023-01-72	2023-01-76	Completed	Machine GG	Machine HH	On Track	2023-01-75 16:00
J073	Job 073	2023-01-73	2023-01-77	In Progress	Machine KK	Machine LL	At Risk	2023-01-74 12:00
J074	Job 074	2023-01-74	2023-01-78	Pending	Machine MM	Machine NN	At Risk	2023-01-75 09:00
J075	Job 075	2023-01-75	2023-01-79	Completed	Machine OO	Machine PP	On Track	2023-01-78 14:00
J076	Job 076	2023-01-76	2023-01-80	In Progress	Machine QQ	Machine RR	At Risk	2023-01-77 11:00
J077	Job 077	2023-01-77	2023-01-81	Pending	Machine TT	Machine YY	At Risk	2023-01-78 08:00
J078	Job 078	2023-01-78	2023-01-82	Completed	Machine ZZ	Machine AA	On Track	2023-01-81 18:00
J079	Job 079	2023-01-79	2023-01-83	In Progress	Machine BB	Machine CC	At Risk	2023-01-80 13:00
J080	Job 080	2023-01-80	2023-01-84	Pending	Machine DD	Machine EE	At Risk	2023-01-81 09:00
J081	Job 081	2023-01-81	2023-01-85	Completed	Machine GG	Machine HH	On Track	2023-01-84 16:00
J082	Job 082	2023-01-82	2023-01-86	In Progress	Machine KK	Machine LL	At Risk	2023-01-83 12:00
J083	Job 083	2023-01-83	2023-01-87	Pending	Machine MM	Machine NN	At Risk	2023-01-84 09:00
J084	Job 084	2023-01-84	2023-01-88	Completed	Machine OO	Machine PP	On Track	2023-01-87 14:00
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J091	Job 091	2023-01-91	2023-01-95	In Progress	Machine KK	Machine LL	At Risk	2023-01-92 12:00
J092	Job 092	2023-01-92	2023-01-96	Pending	Machine MM	Machine NN	At Risk	2023-01-93 09:00
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J094	Job 094	2023-01-94	2023-01-98	In Progress	Machine QQ	Machine RR	At Risk	2023-01-95 11:00
J095	Job 095	2023-01-95	2023-01-99	Pending	Machine TT	Machine YY	At Risk	2023-01-96 08:00
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J097	Job 097	2023-01-97	2023-01-101	In Progress	Machine BB	Machine CC	At Risk	2023-01-98 13:00
J098	Job 098	2023-01-98	2023-01-102	Pending	Machine DD	Machine EE	At Risk	2023-01-99 09:00
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J101	Job 101	2023-01-101	2023-01-105	Pending	Machine MM	Machine NN	At Risk	2023-01-102 09:00
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J113	Job 113	2023-01-113	2023-01-117	Pending	Machine TT	Machine YY	At Risk	2023-01-114 08:00
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J115	Job 115	2023-01-115	2023-01-119	In Progress	Machine BB	Machine CC	At Risk	2023-01-116 13:00
J116	Job 116	2023-01-116	2023-01-120	Pending	Machine DD	Machine EE	At Risk	2023-01-117 09:00
J117	Job 117	2023-01-117	2023-01-121	Completed	Machine GG	Machine HH	On Track	2023-01-118 16:00
J118	Job 118	2023-01-118	2023-01-122	In Progress	Machine KK	Machine		

Manufacturing Process Planning

## **Bill of Materials**

# Data Integration Challenges



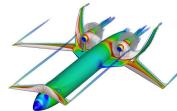
Design

# Data Integration Challenges

A AUTOCAD



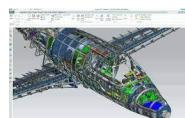
I AUTODESK<sup>®</sup> INVENTOR<sup>®</sup>



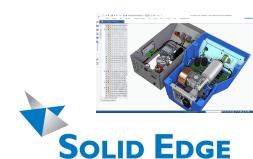
creo<sup>®</sup>



NX

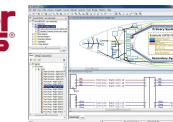


DS CATIA



SOLID EDGE

Mentor Graphics<sup>®</sup>



DS SOLIDWORKS



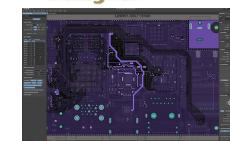
pads<sup>®</sup>  
personal automated design system



cadence<sup>®</sup>



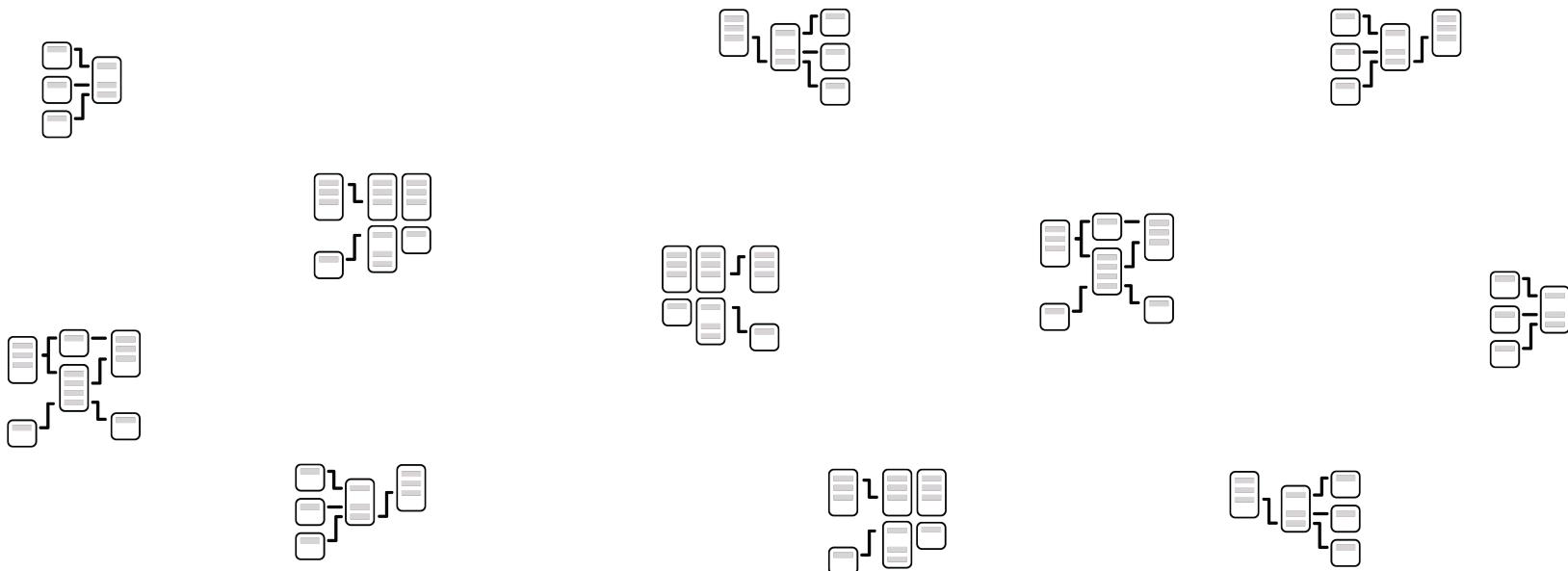
Altium<sup>®</sup>  
Designer



# Data Integration Challenges



# Data Integration Challenges



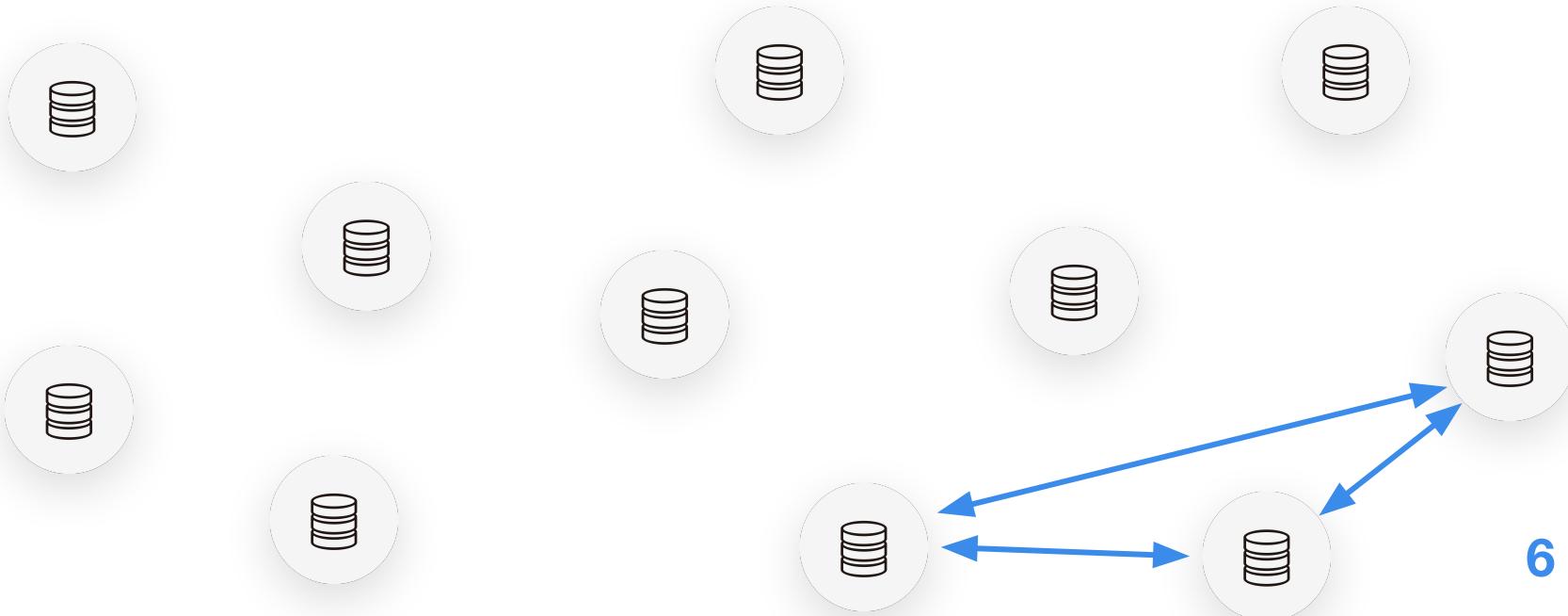
# Data Integration Challenges



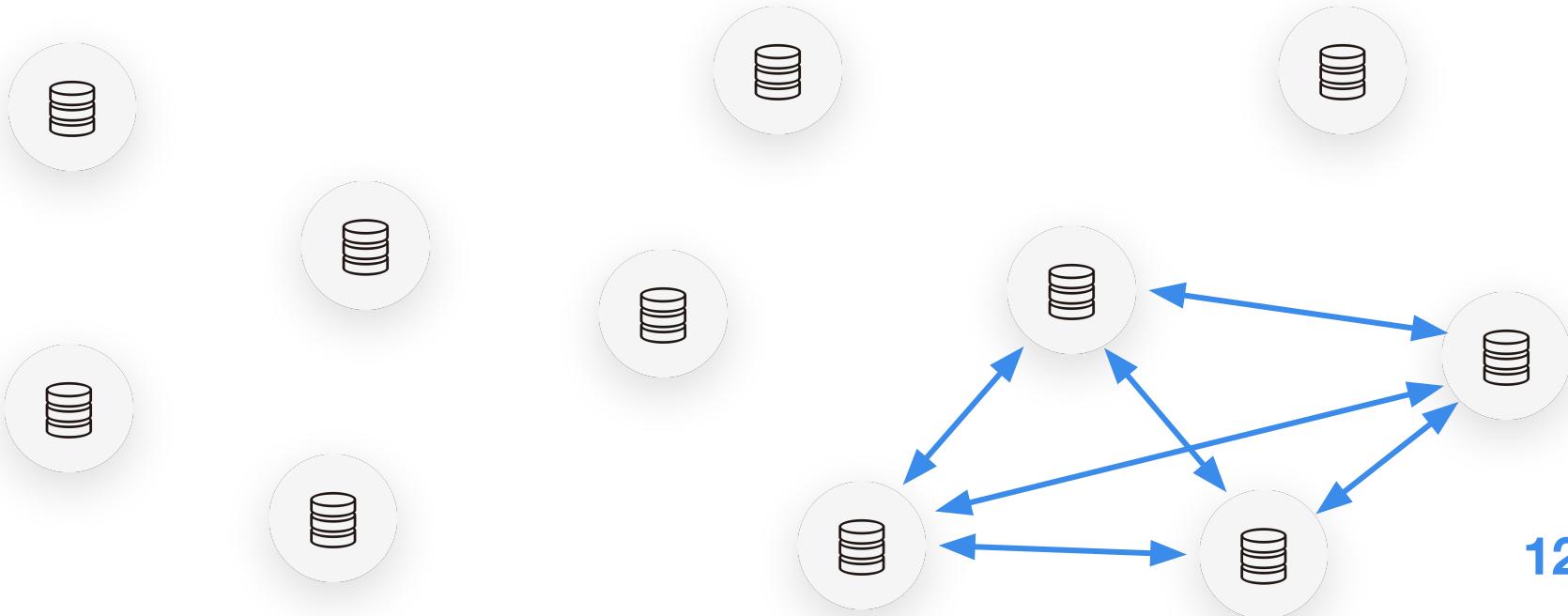
# Data Integration Challenges



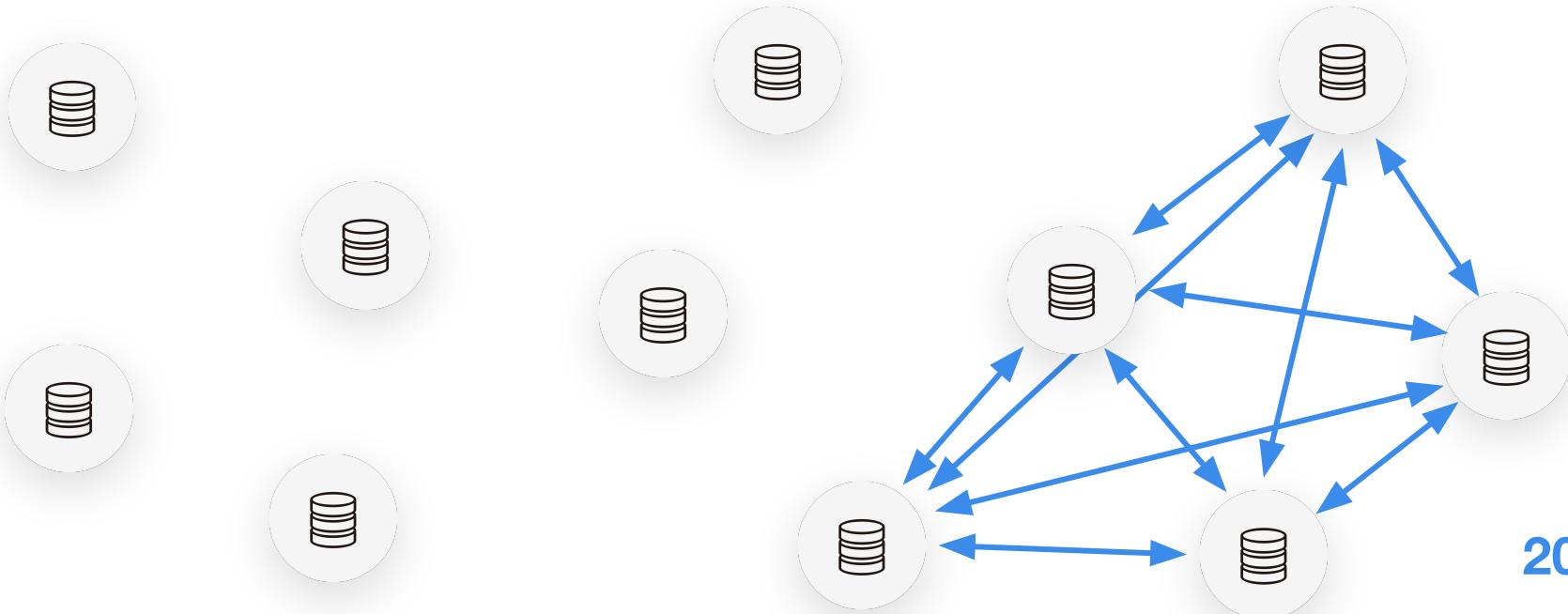
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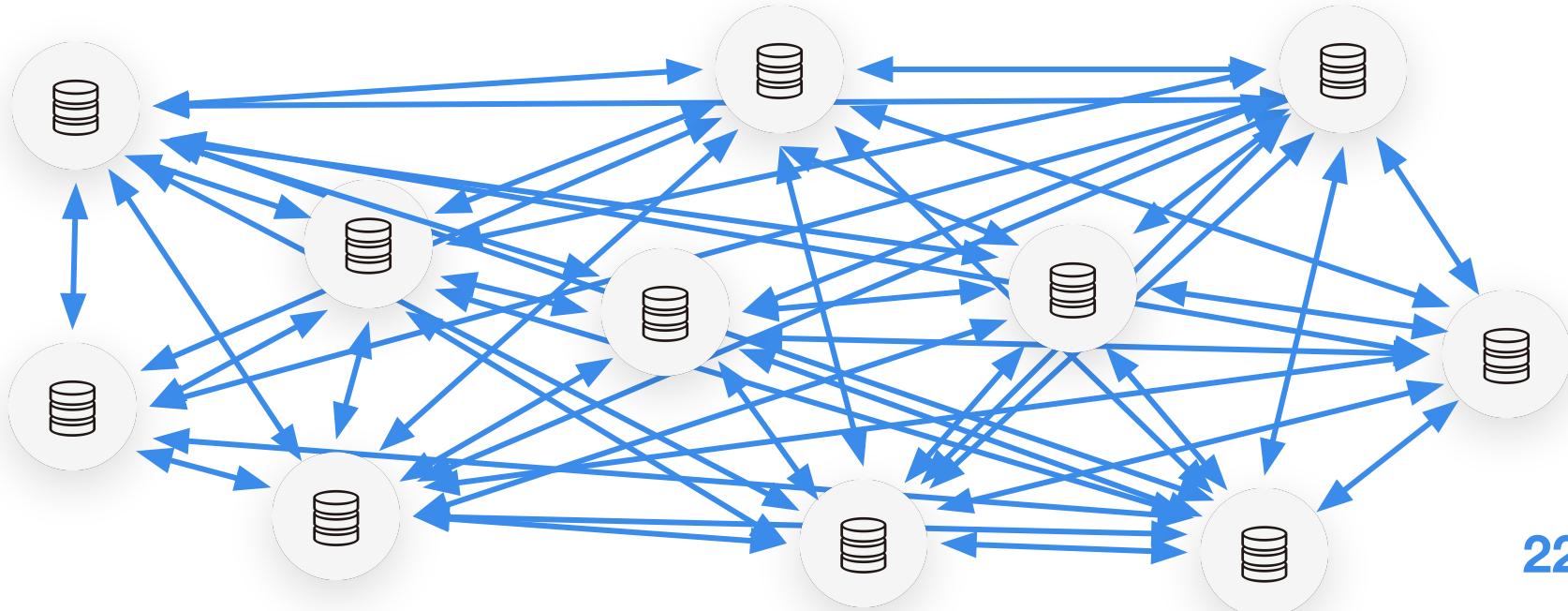
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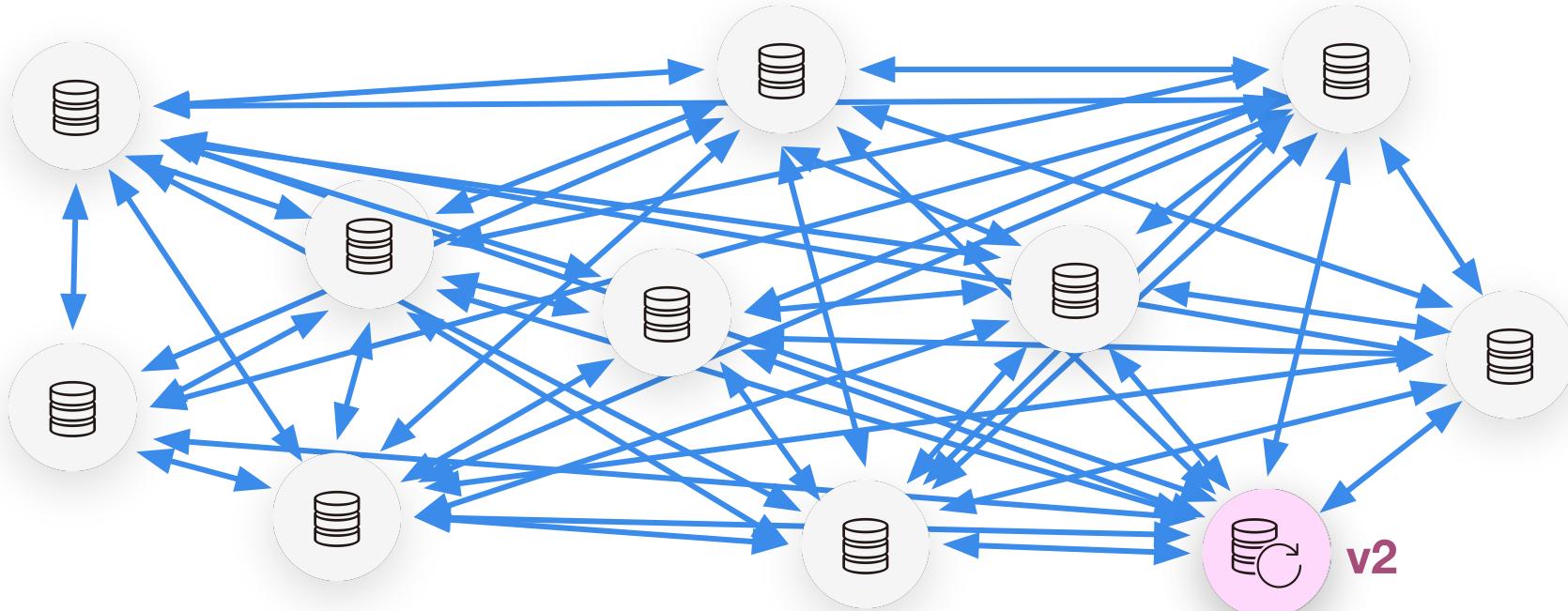
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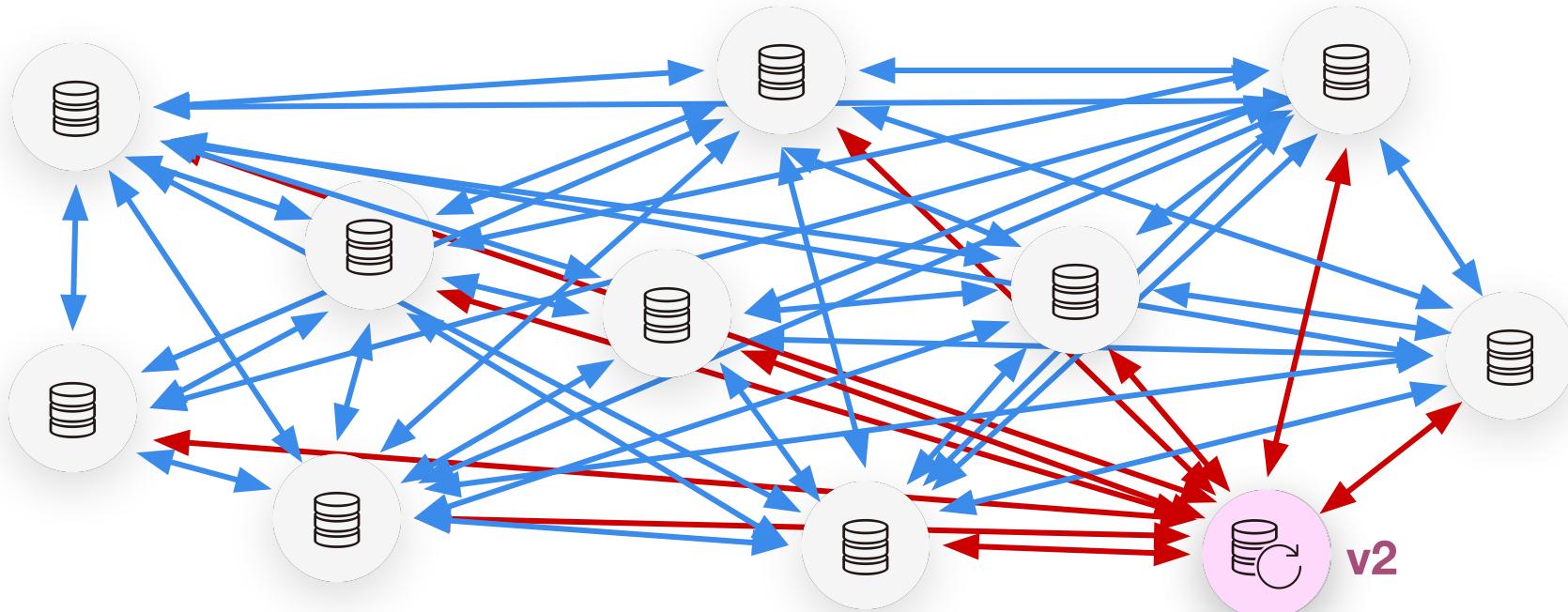
# Data Integration Challenges



# Data Integration Challenges



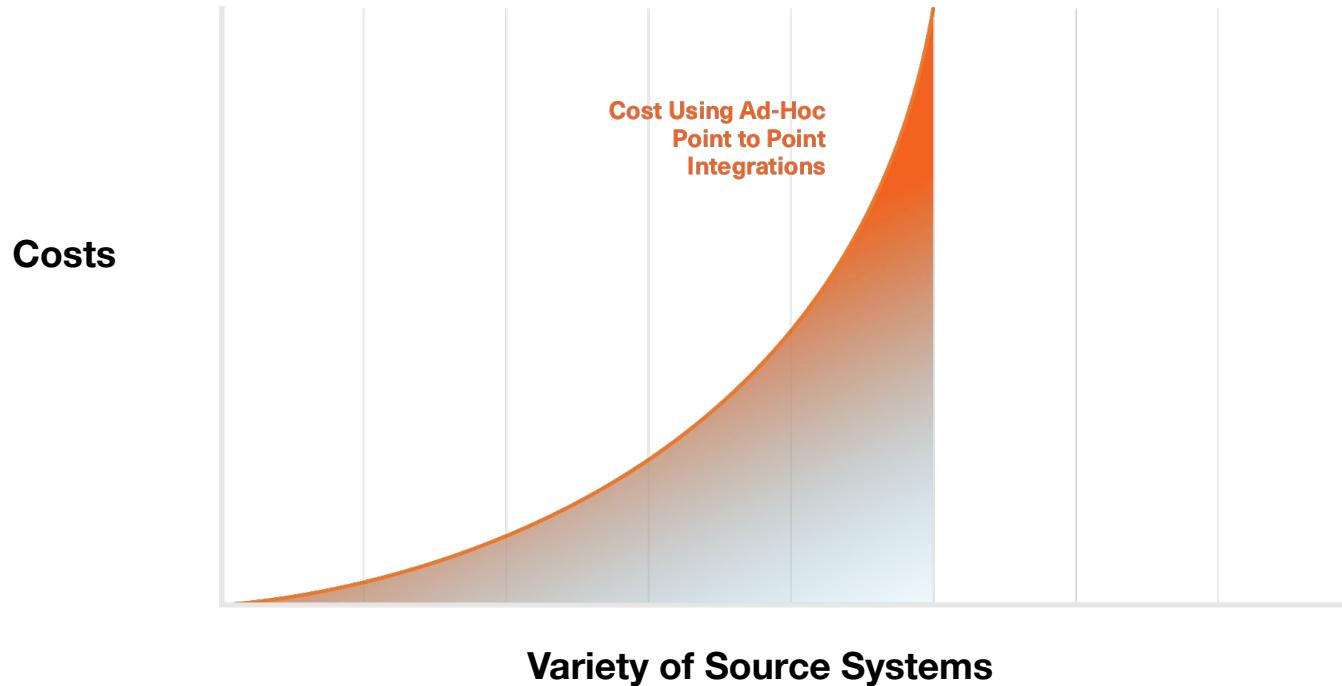
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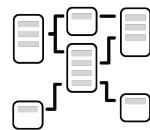
# Data Integration Challenges

$\sim N^2$

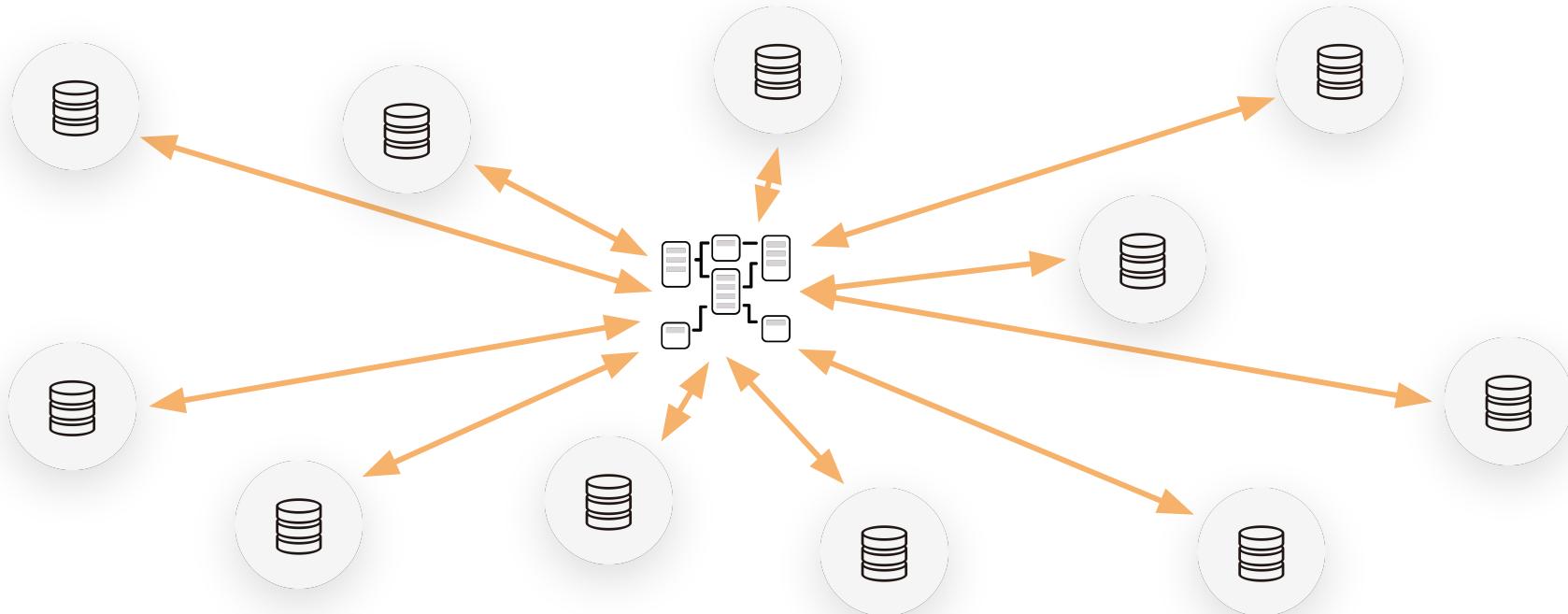
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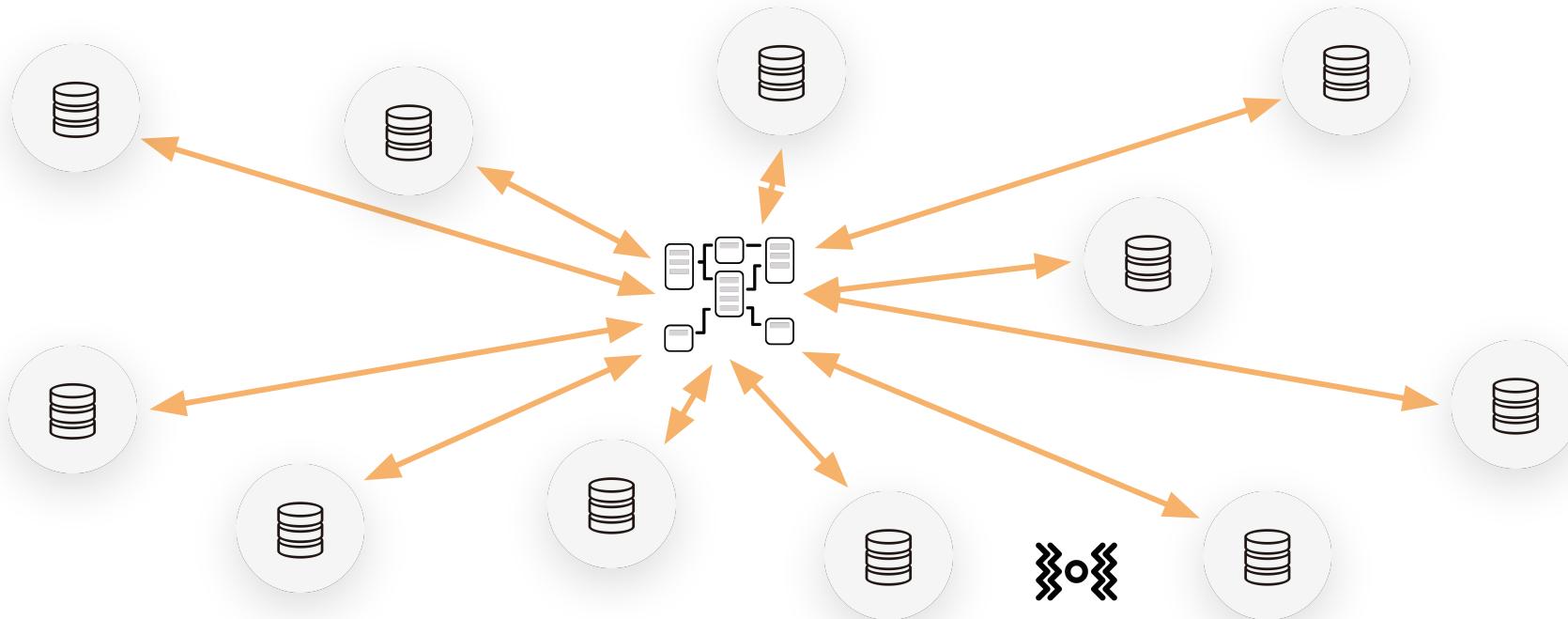
# Data Integration Challenges



# Data Integration Challenges



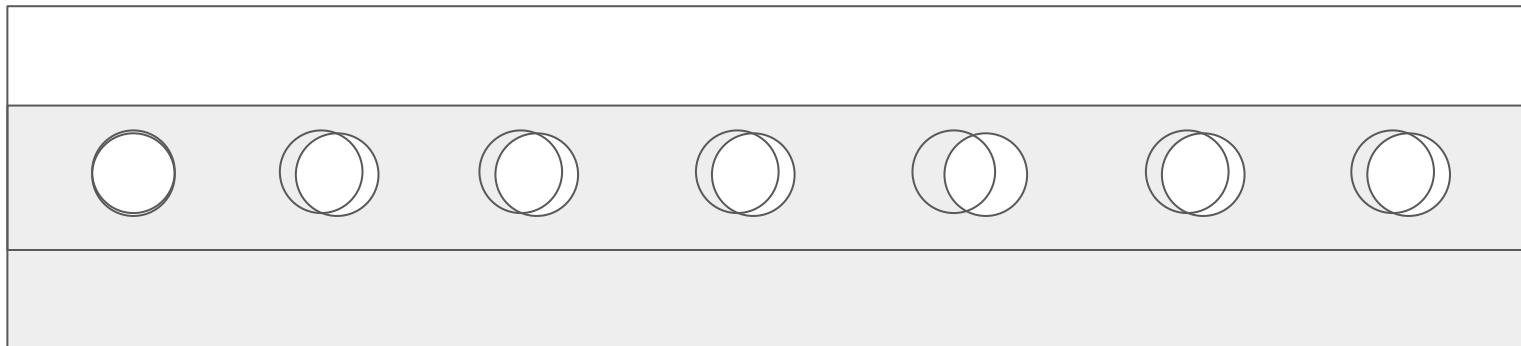
# Data Integration Challenges



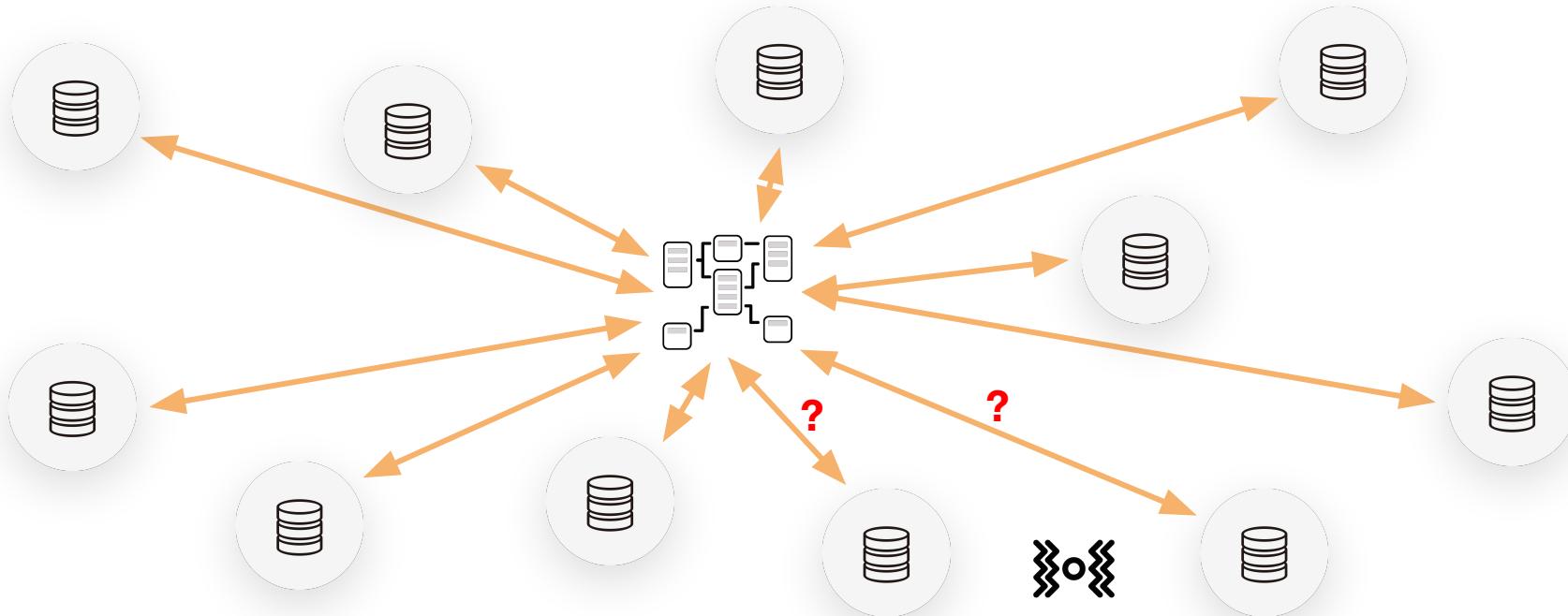
# Data Integration Challenges



# Data Integration Challenges

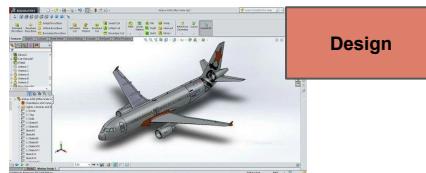


# Data Integration Challenges

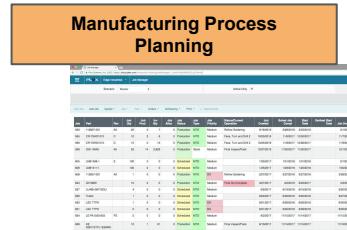


# Data Integration Challenges

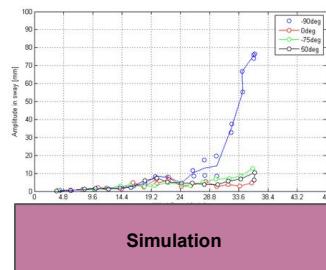
<<requirement>>	
Climb: One-engine-inoperative	
Requirement	
FEDERAL AVIATION ADMINISTRATION (FAA) Title 14, Chapter 1, Subchapter C 25.121	
... (a) Takeoff; landing gear extended... the steady gradient of column... not less than 0.5 percent... for four-engine airplanes	



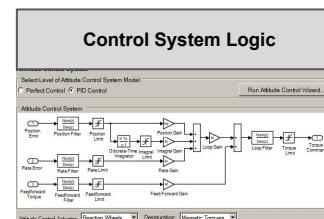
Design



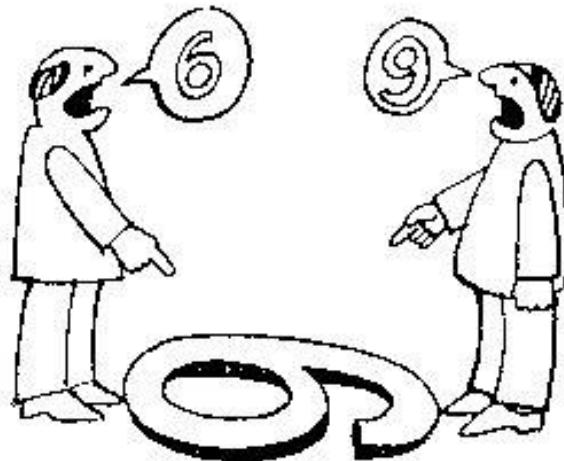
Test Case	<<testcase>> Climb: One-engine-inoperative
Perform simulation under conditions...	



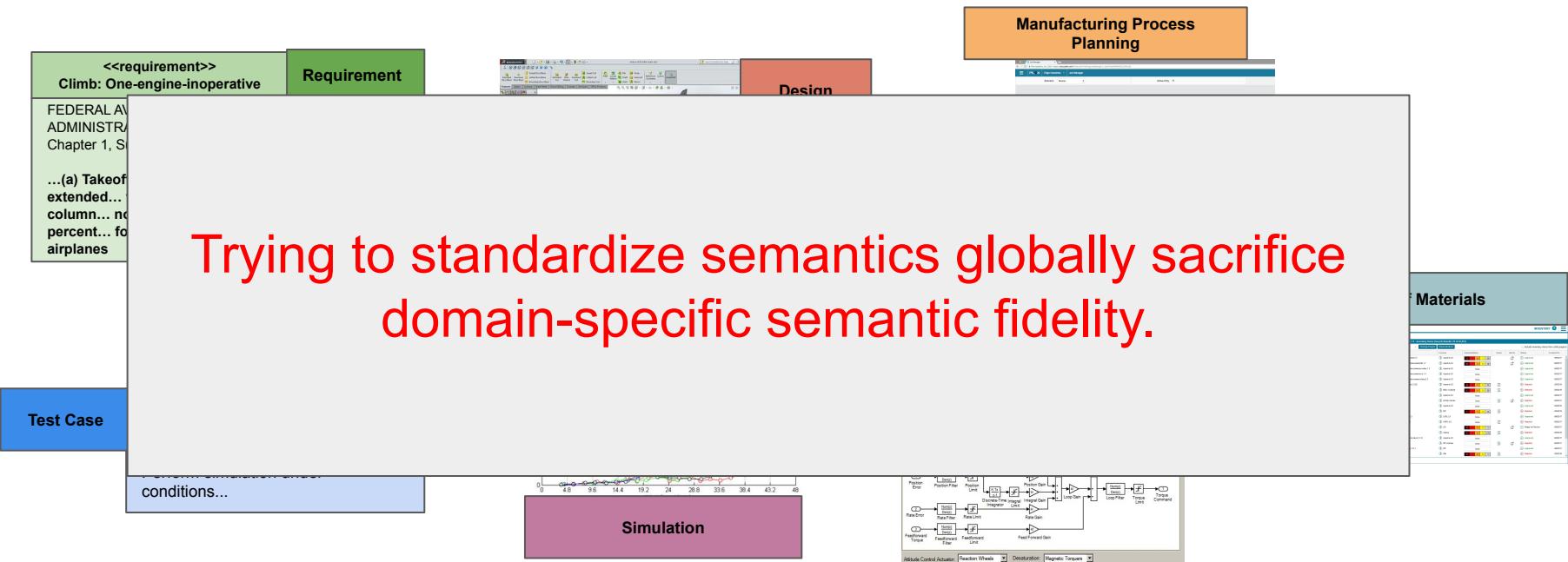
Simulation



# Data Integration Challenges



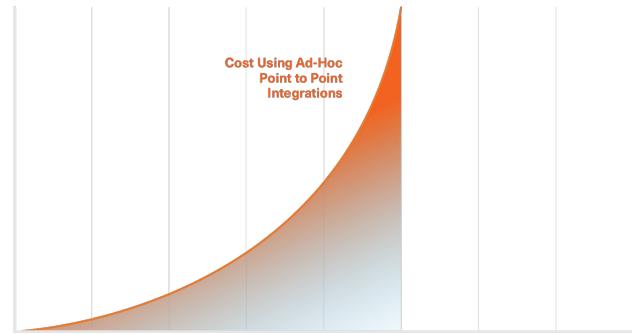
# Data Integration Challenges



# Data Integration Challenges

Sacrifice domain-specific semantic fidelity.

VS

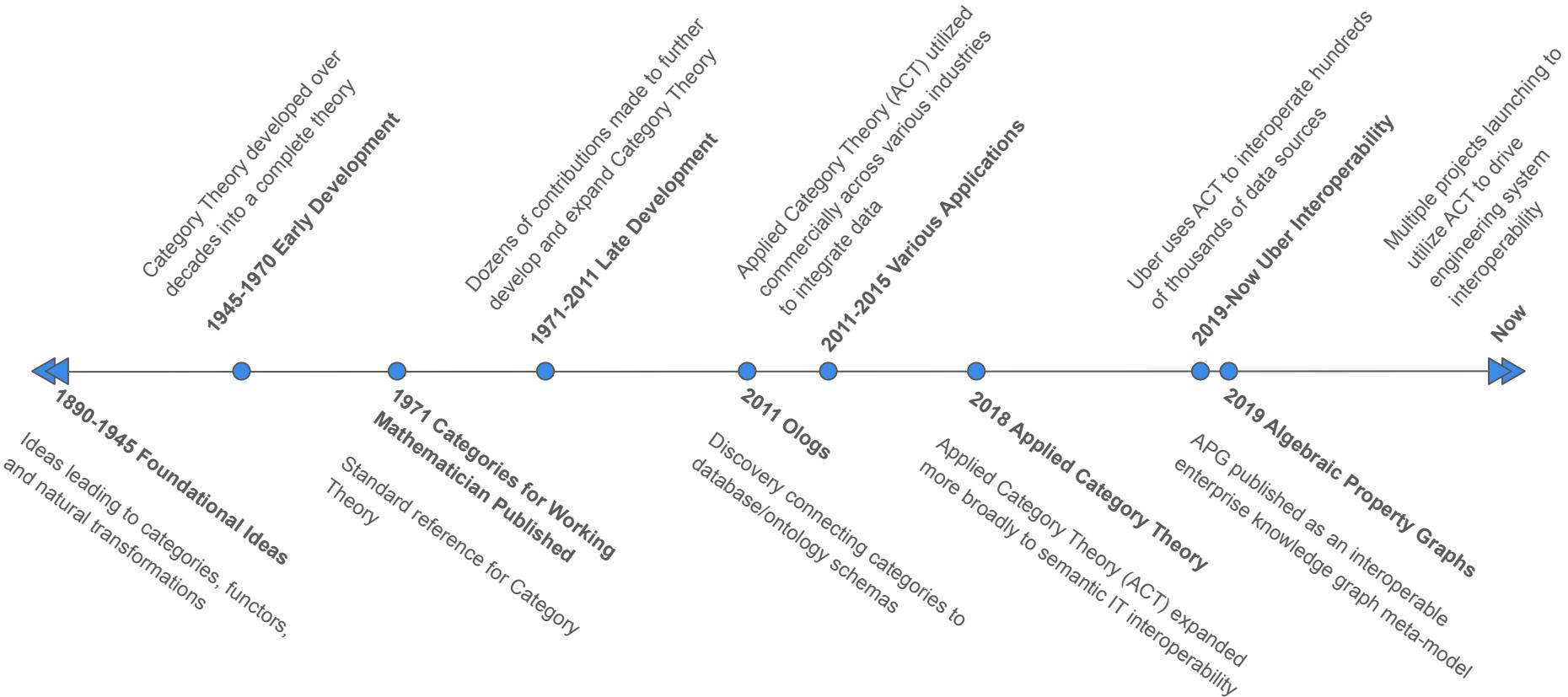




# Semantic Data Interoperability

Enabled by Categorical Mathematics

# Category Theory History



# Category Theory History

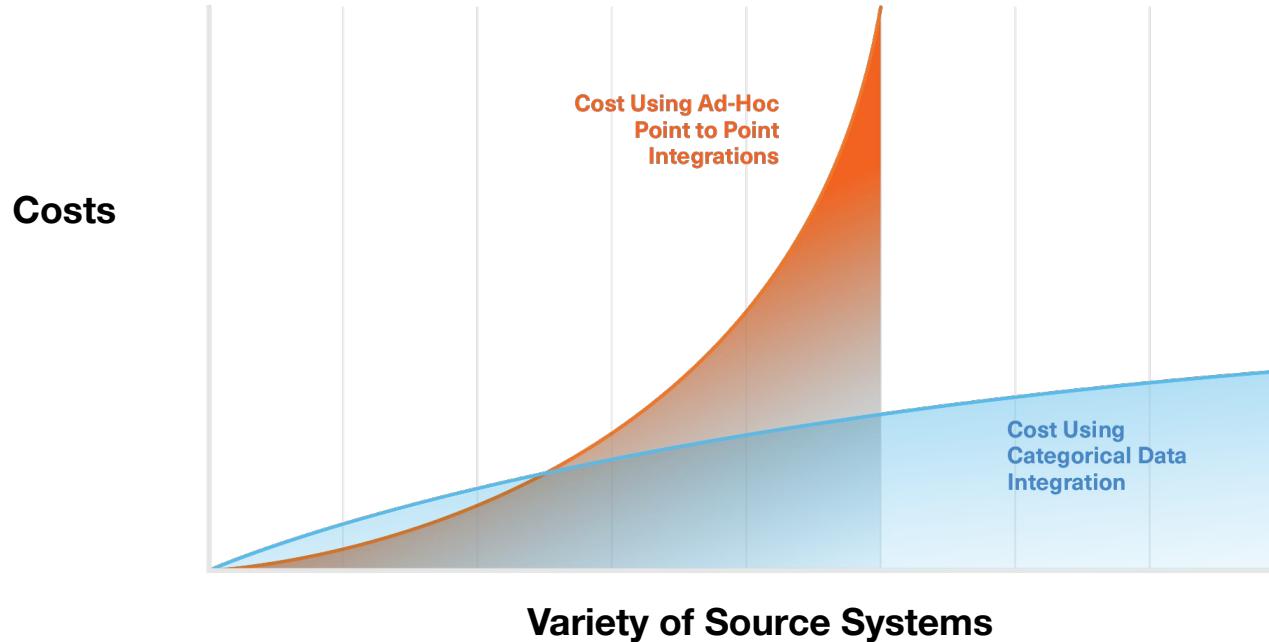


David Spivak  
MIT



Ryan Wisnesky  
MIT

# Foundationally Better Cost Scaling



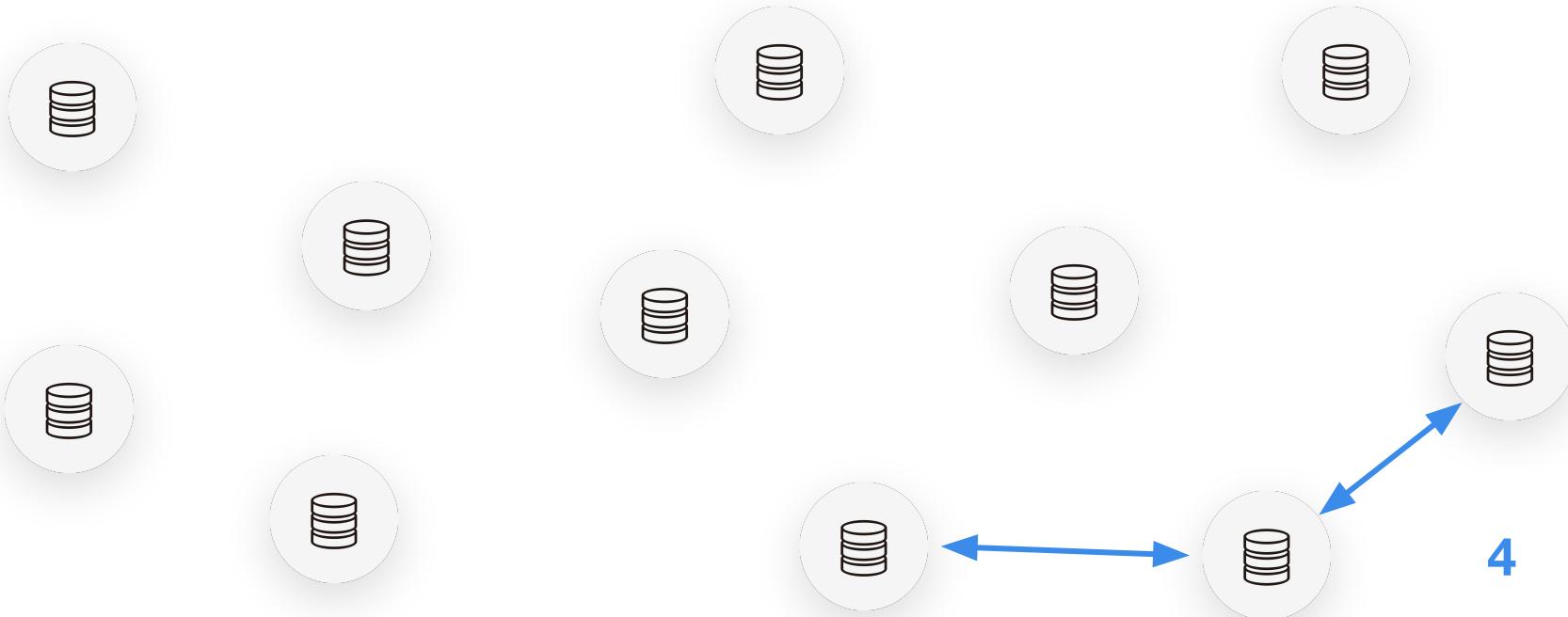
# Foundationally Better Cost Scaling



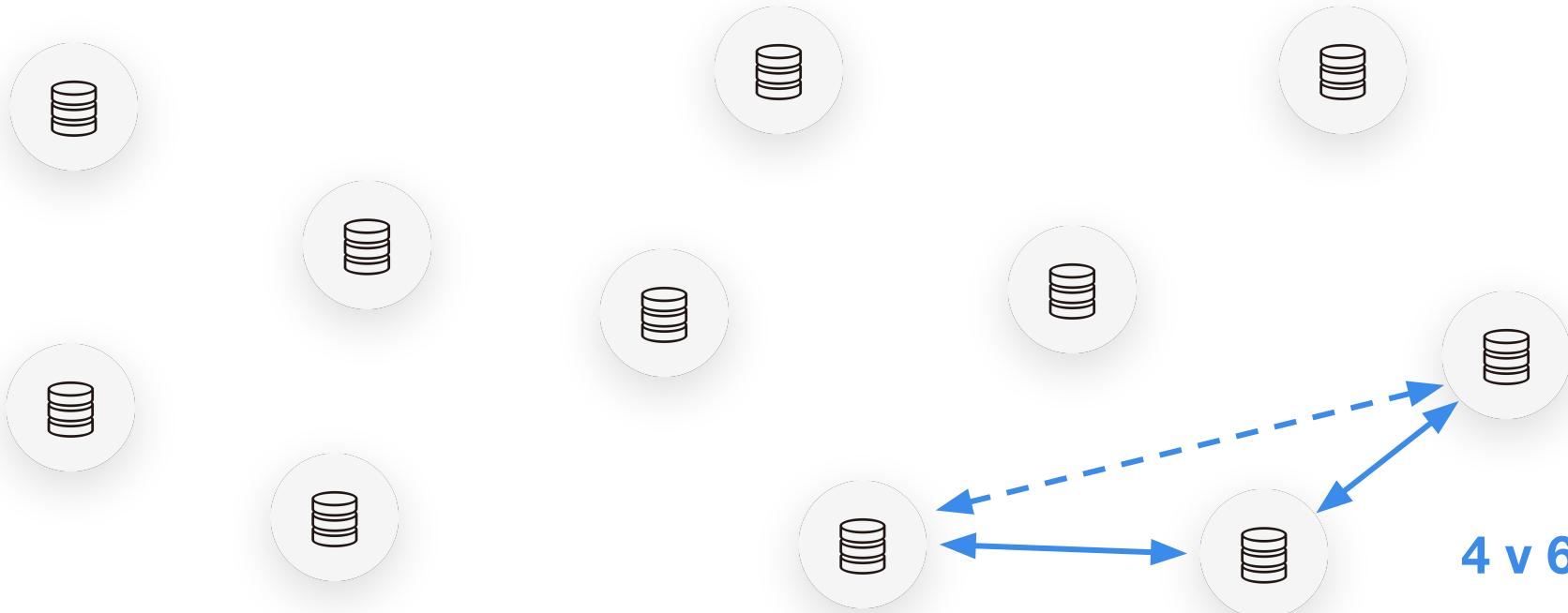
# Foundationally Better Cost Scaling



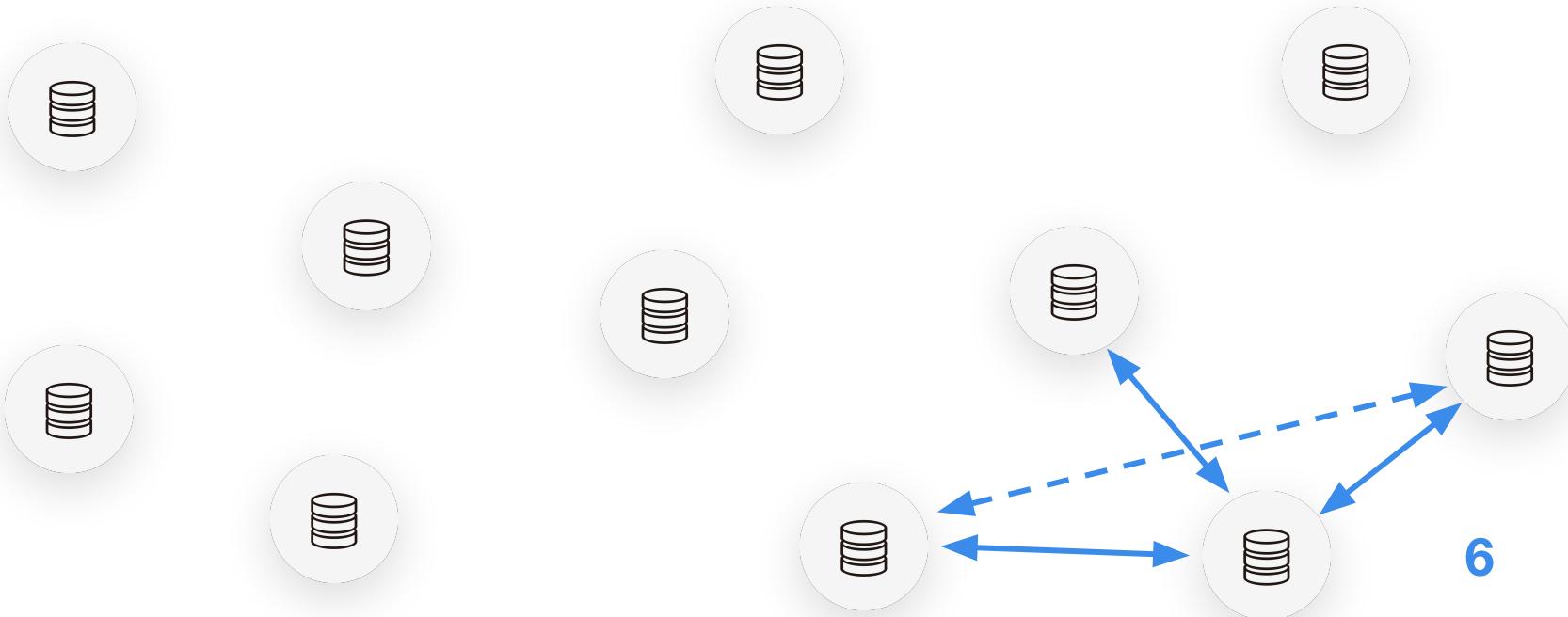
# Foundationally Better Cost Scaling



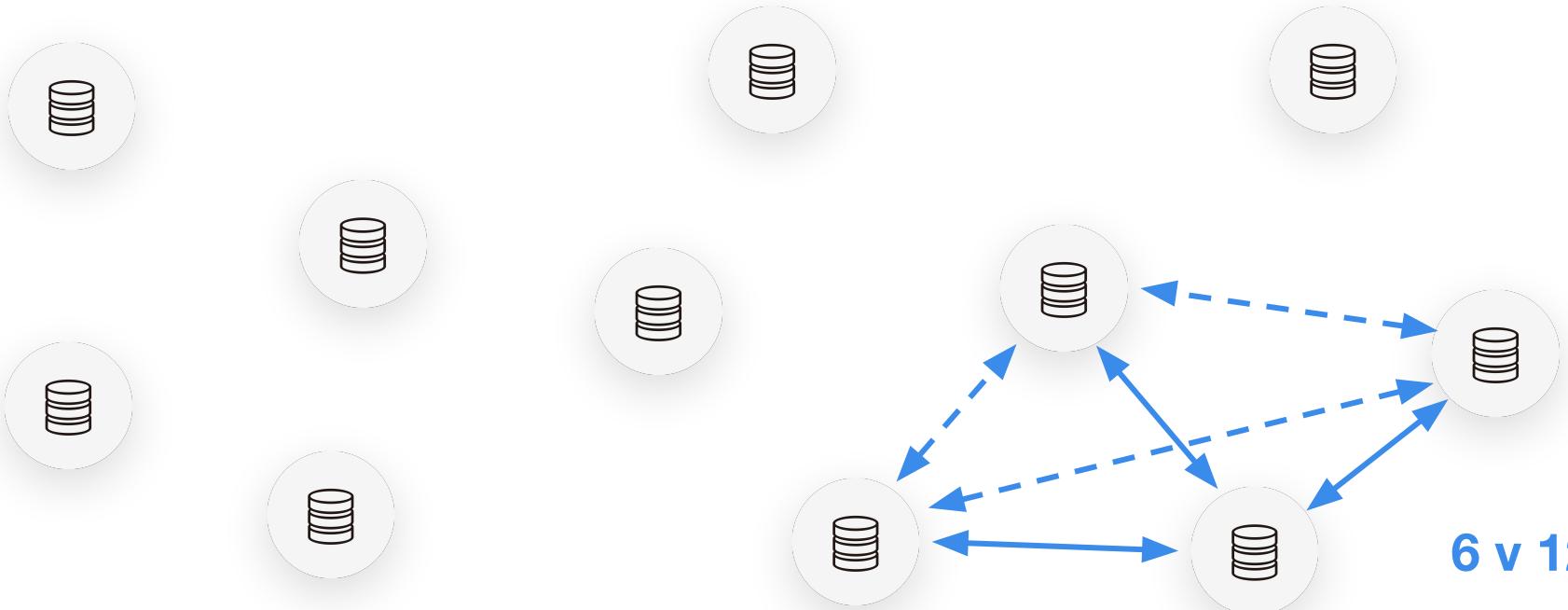
# Foundationally Better Cost Scaling



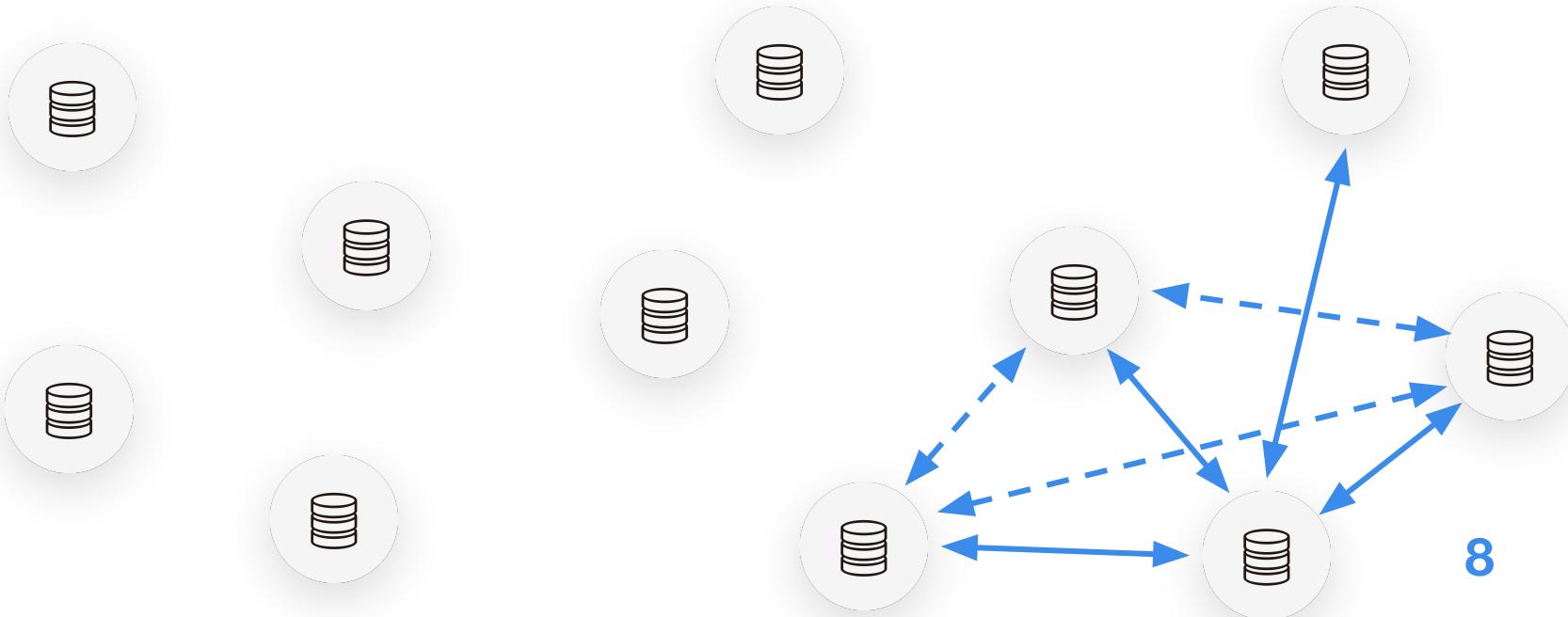
# Foundationally Better Cost Scaling



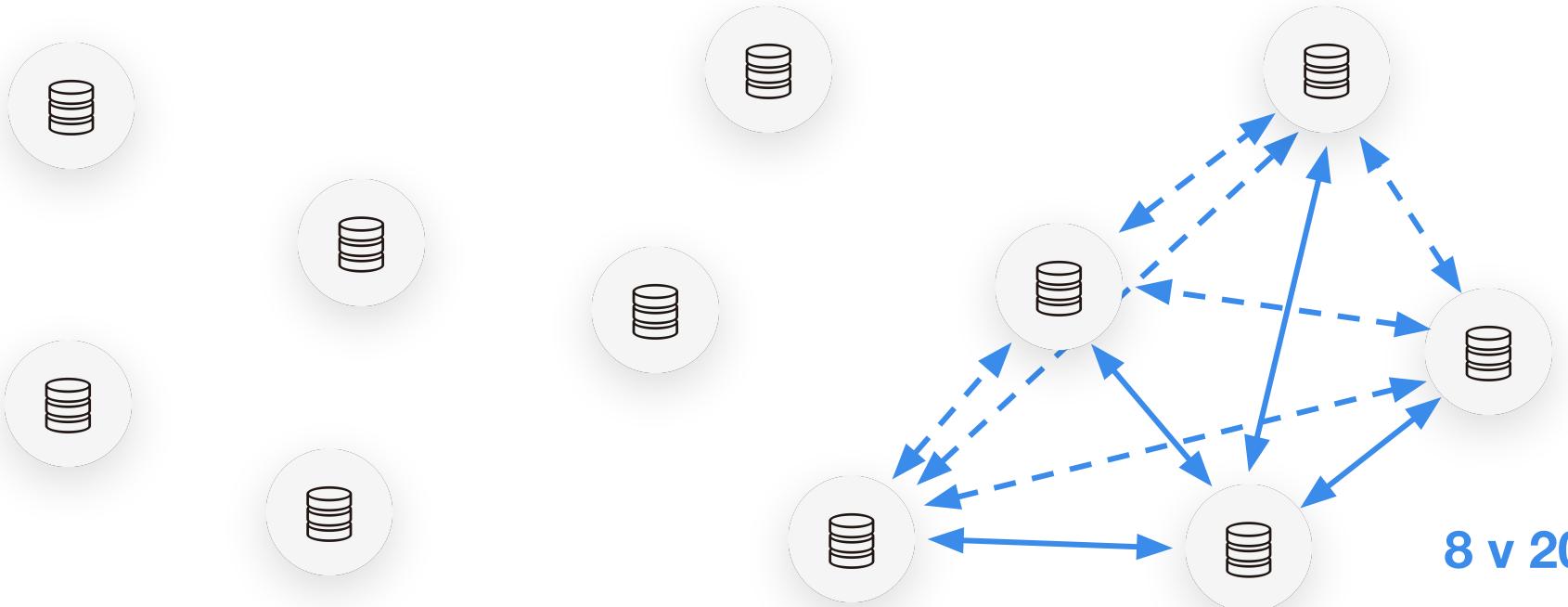
# Foundationally Better Cost Scaling



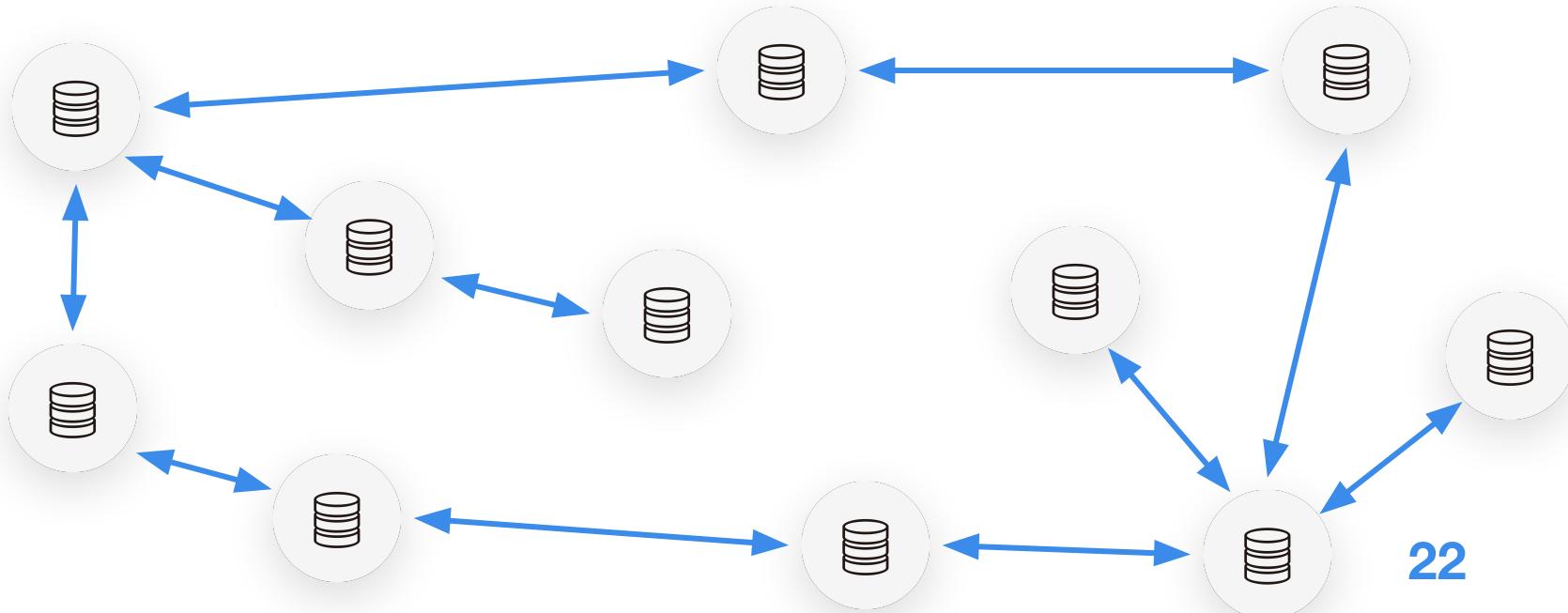
# Foundationally Better Cost Scaling



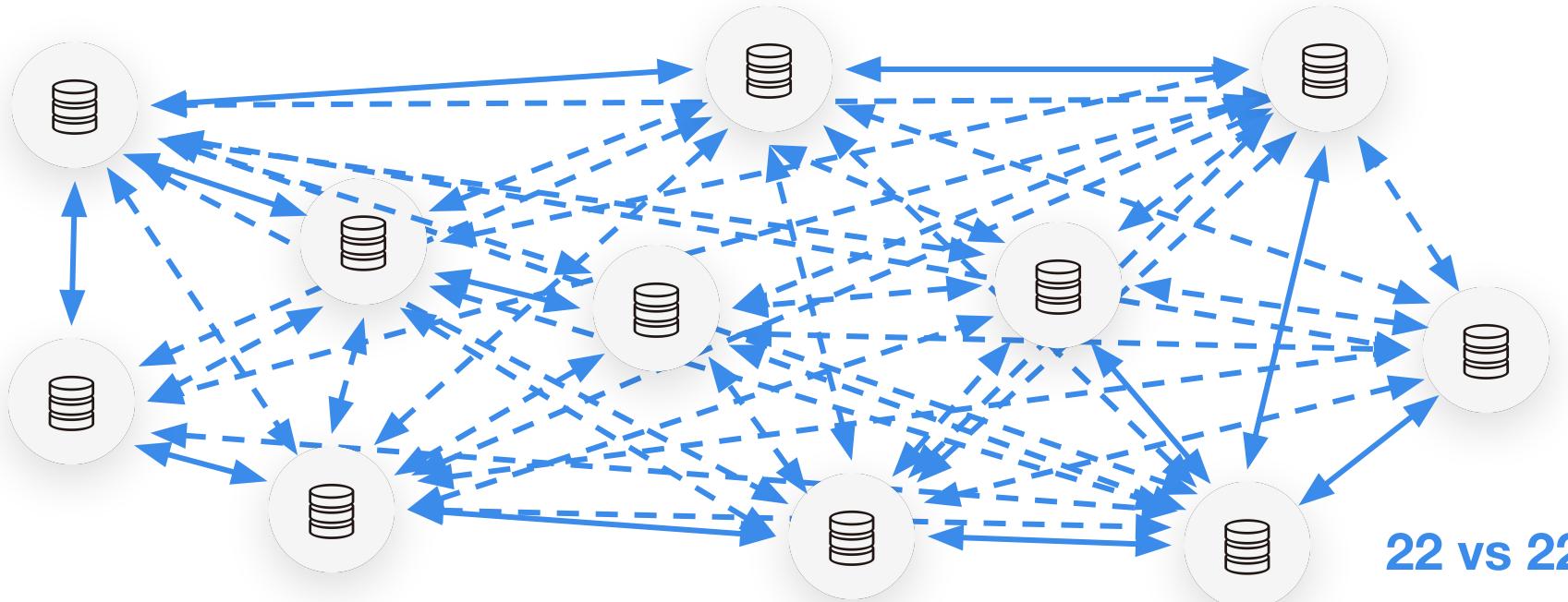
# Foundationally Better Cost Scaling



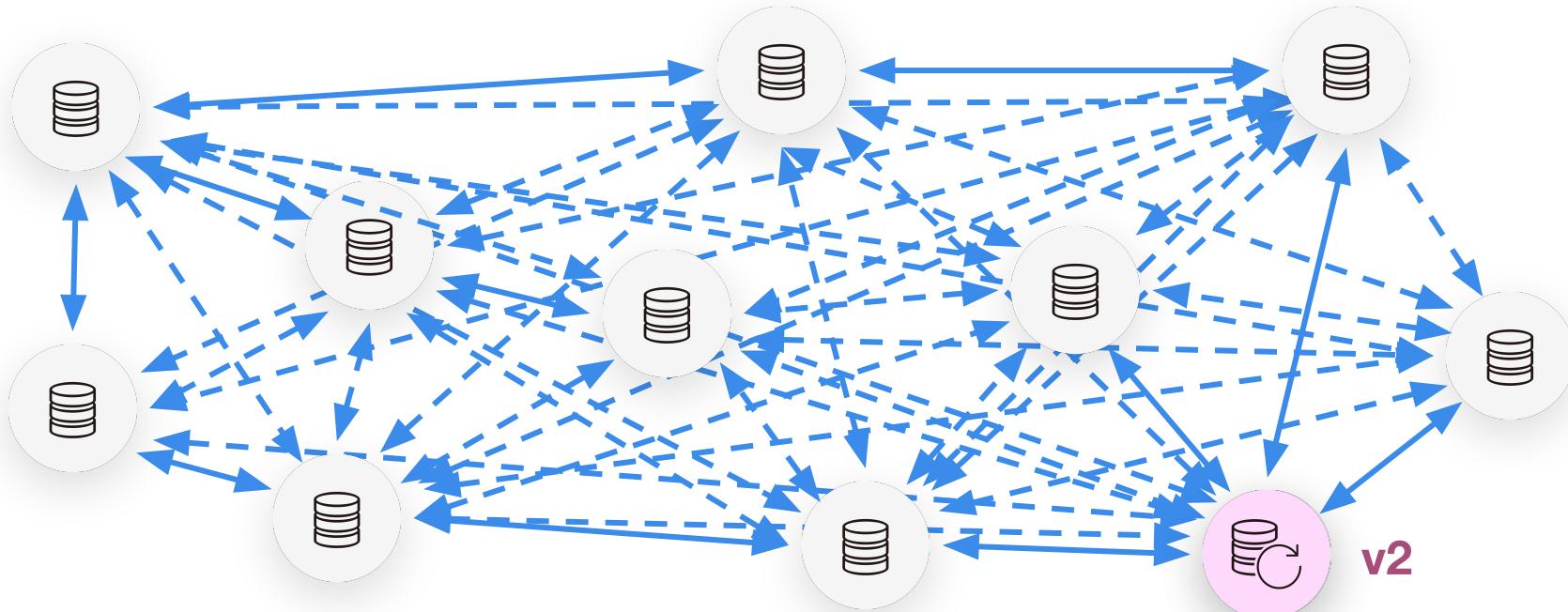
# Foundationally Better Cost Scaling



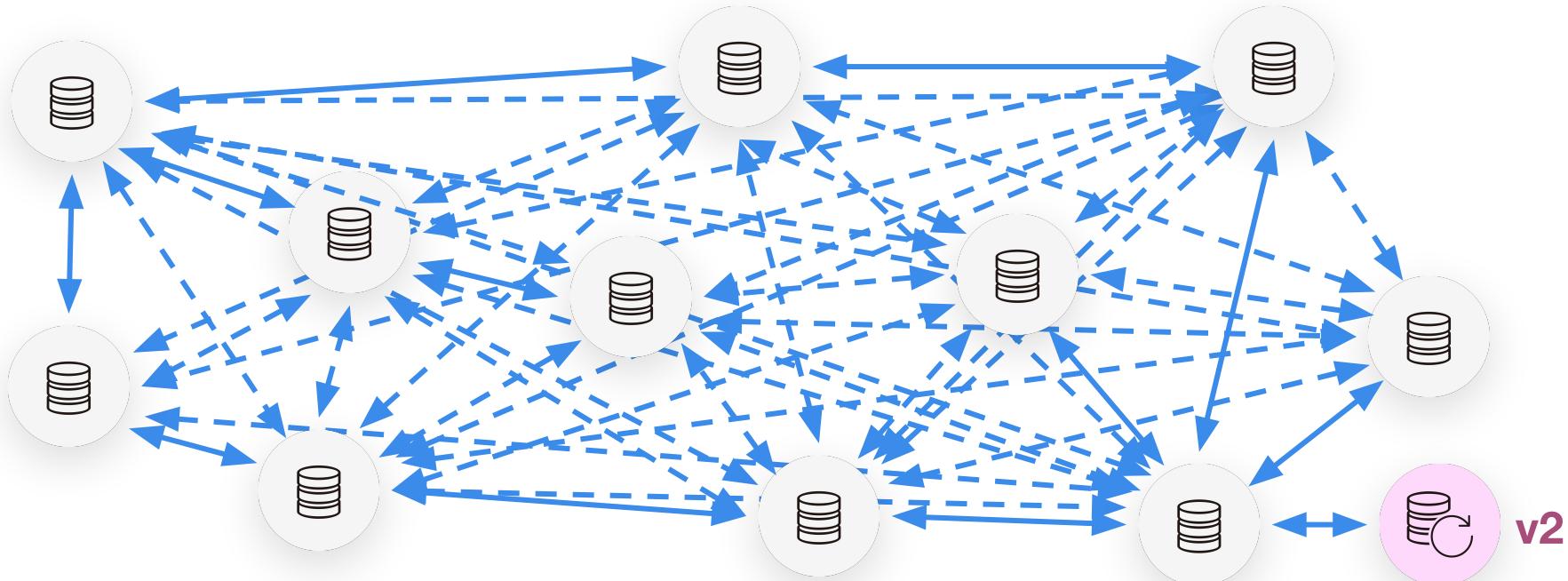
# Foundationally Better Cost Scaling



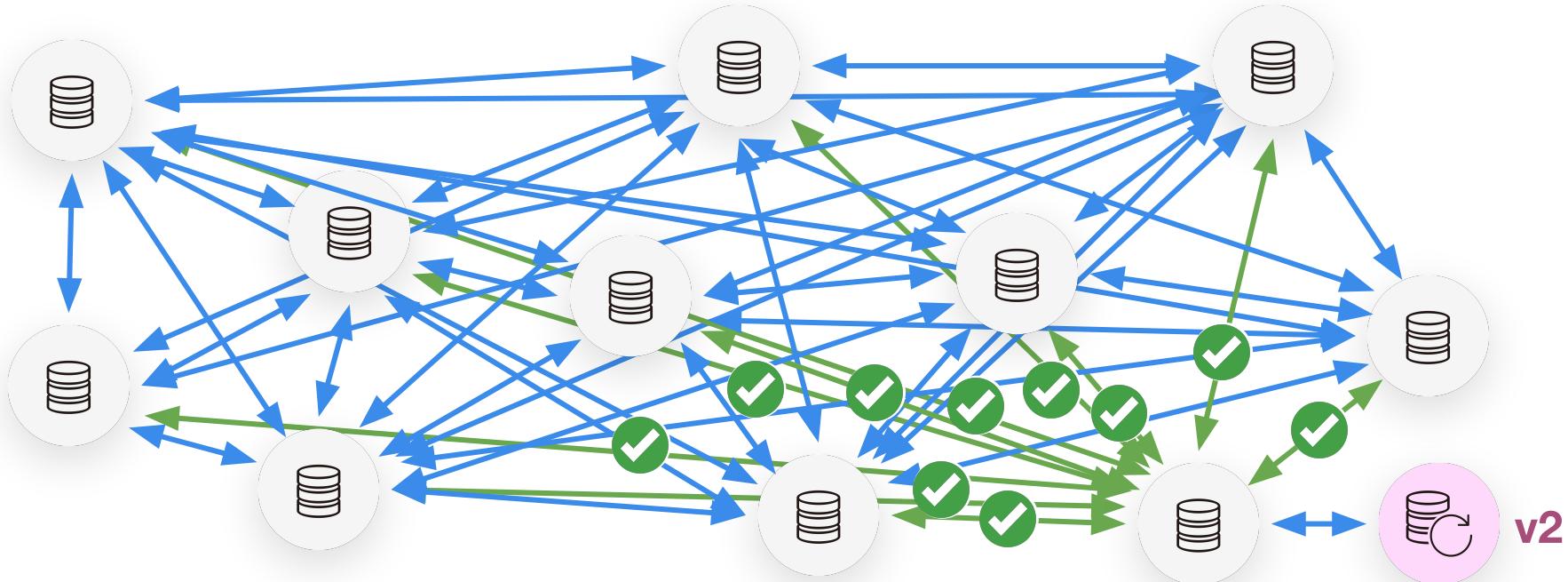
# Foundationally Better Cost Scaling



# Foundationally Better Cost Scaling

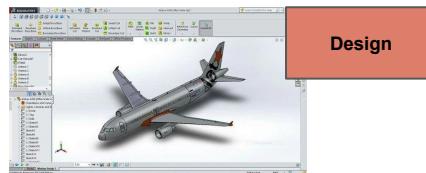


# Foundationally Better Cost Scaling



# New Data Integration Paradigm

<<requirement>>	
Climb: One-engine-inoperative	
Requirement	
FEDERAL AVIATION ADMINISTRATION (FAA) Title 14, Chapter 1, Subchapter C 25.121	
(a) Takeoff; landing gear extended... the steady gradient of column... not less than 5 percent... for four-engine airplanes	

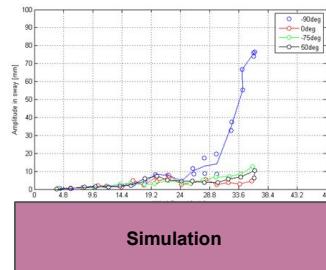


Design

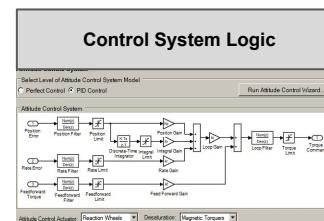


Manufacturing Process Planning

Test Case	<<testcase>> Climb: One-engine-inoperative
Perform simulation under conditions...	



Simulation



Control System Logic



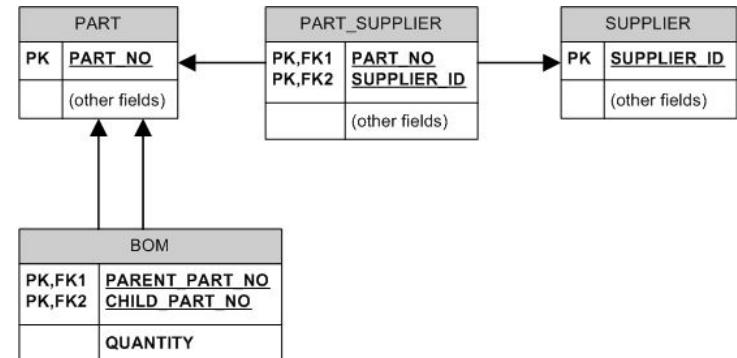
Bill of Materials

# New Data Integration Paradigm

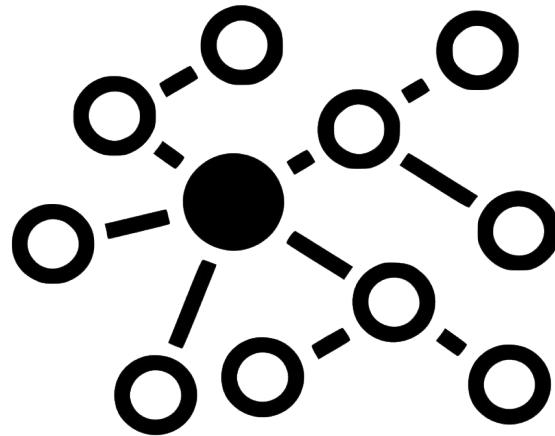
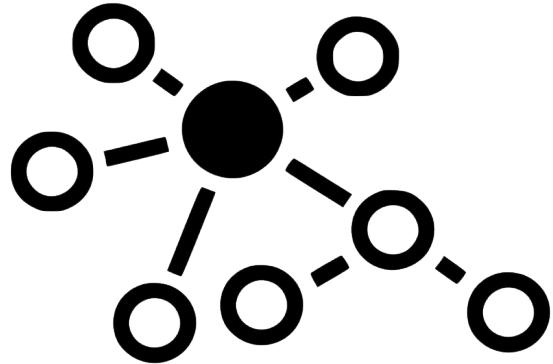
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    <property name="Section" val="7.069e-006m2" />
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    <property name="Length" val="115.122mm" />
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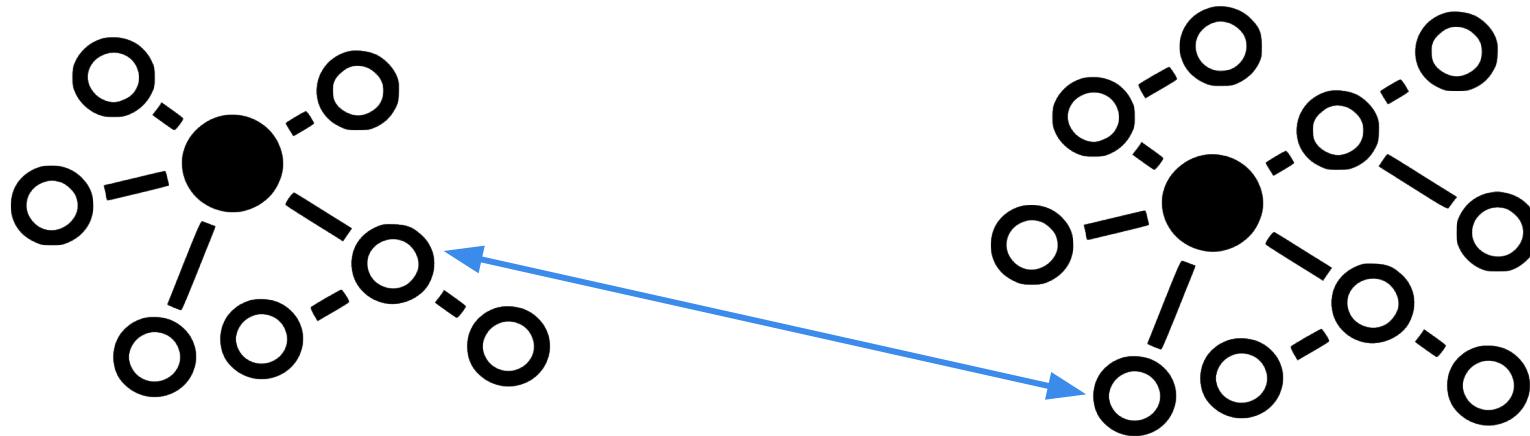
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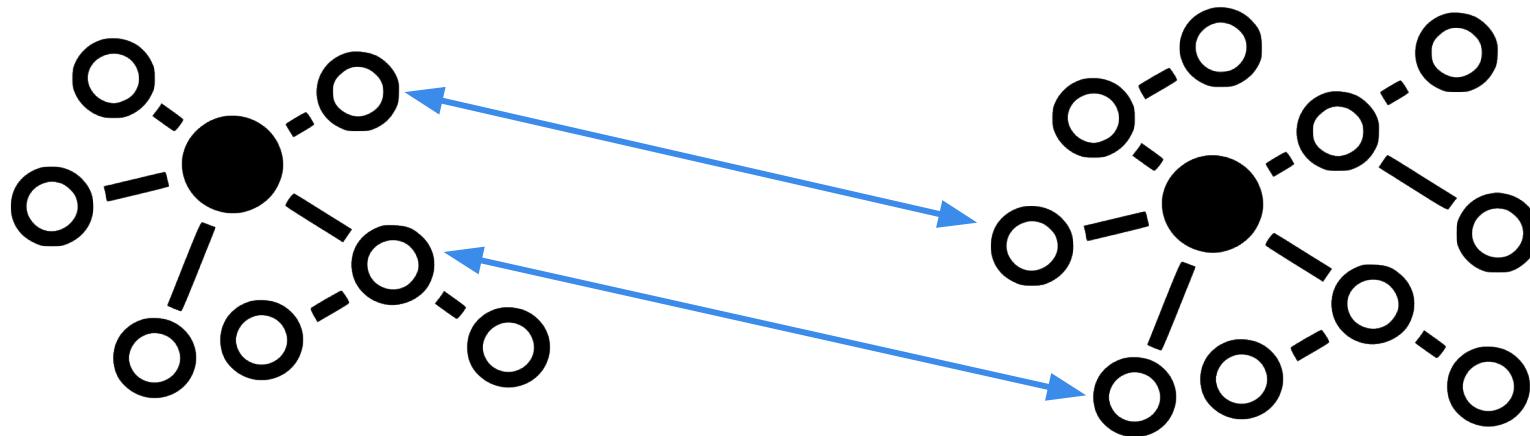
# New Data Integration Paradigm



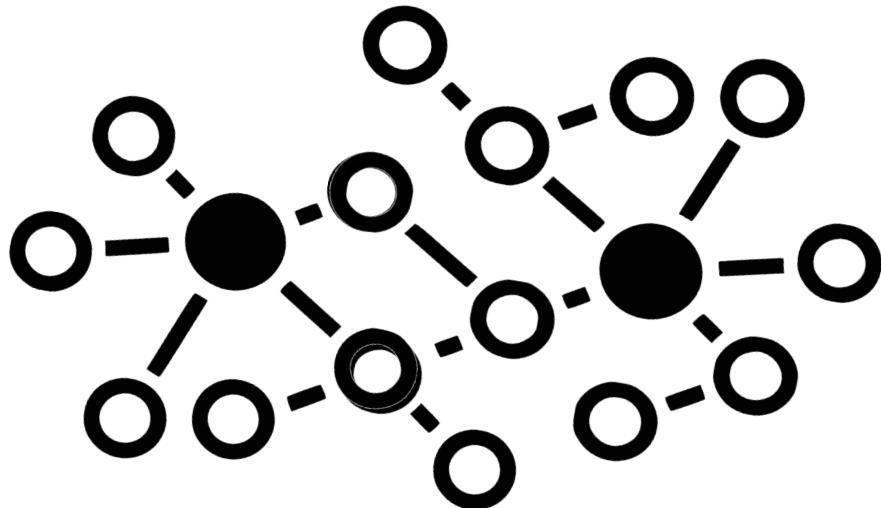
# New Data Integration Paradigm



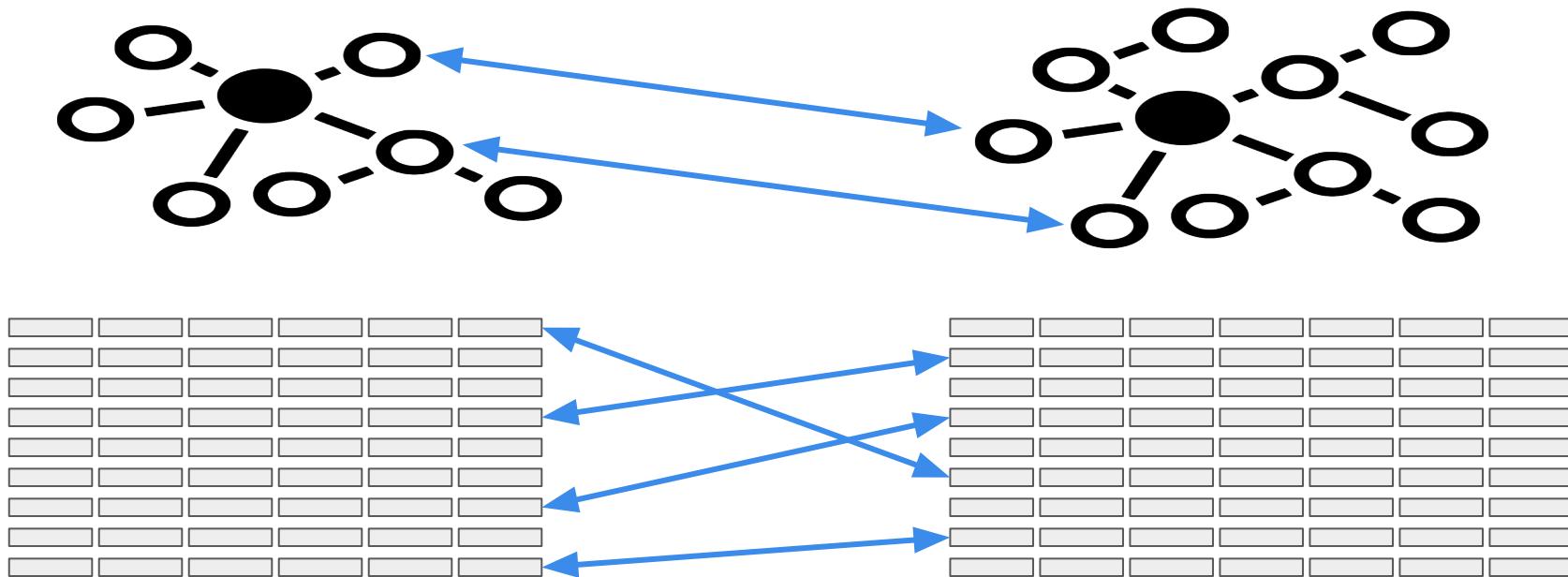
# New Data Integration Paradigm



# New Data Integration Paradigm



# New Data Integration Paradigm

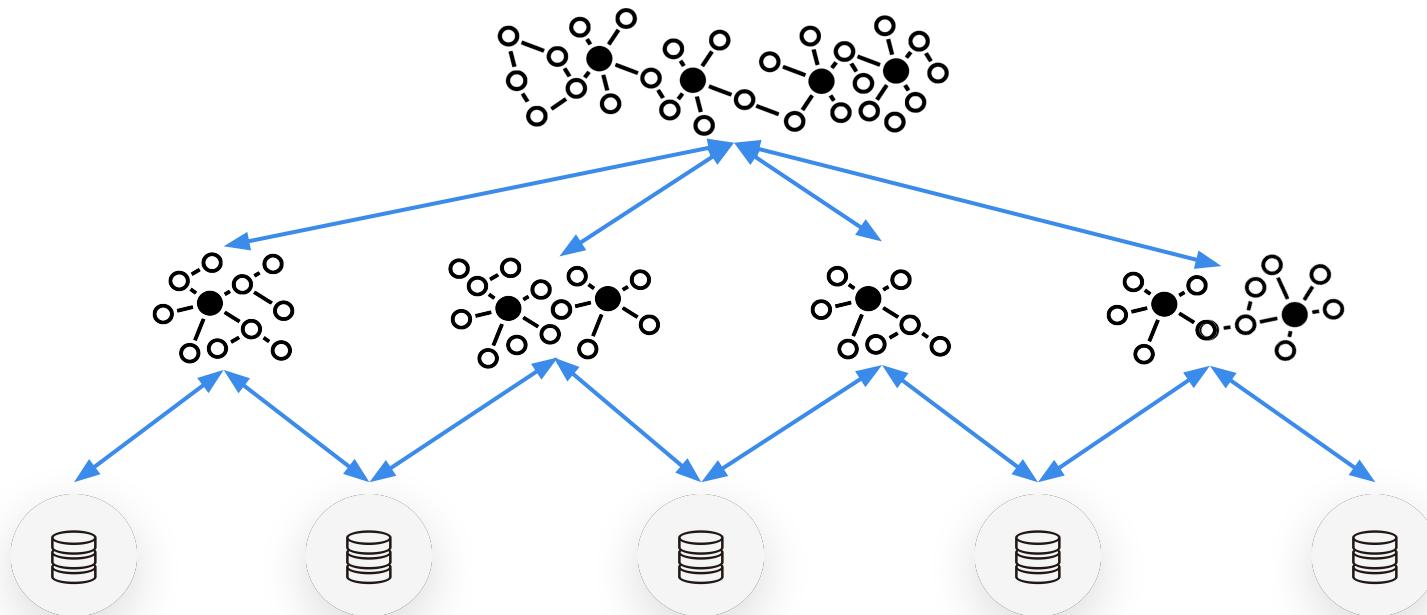


# Automatically Compose Data Sources

## Required Inputs

- Data Schema
- Data Records
- Schema Links (as schema)
- Record Links (as records)
- Rules (declarative)

# Automatically Compose Data Sources



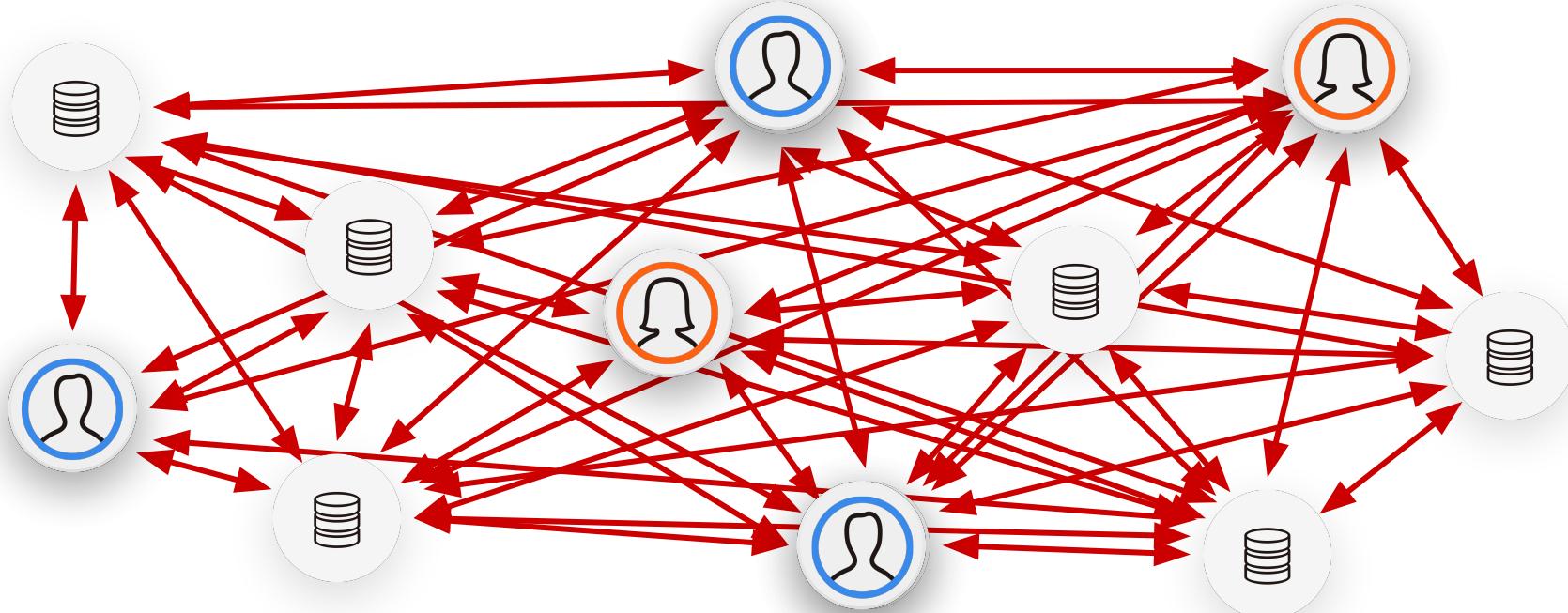
Data, Concepts, Relationships & Rules AKA Records, Attributes, References & Constraints

# Conexus Enables New Paradigm

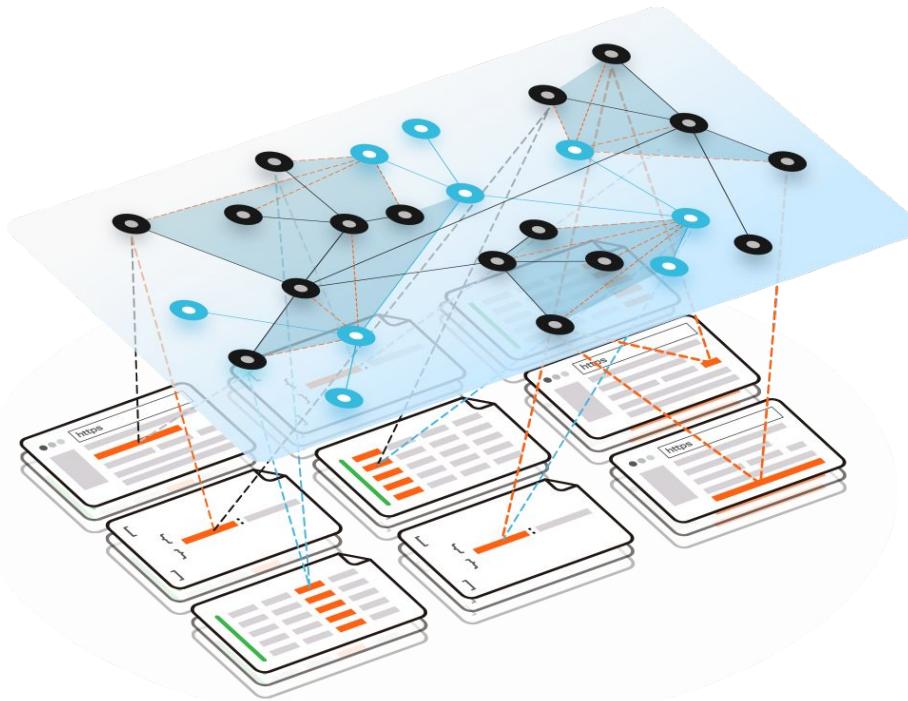
## Exploiting Categorical Mathematics

- Automate composition of integrations
- Merge data models, schemas and ontologies safely
- Exchange and consolidate data
- Enable forward and backward compatibility
- Curate and add sources incrementally
- Enforce global and domain-specific rules
- Machine-verify integrity of integrations
- Quantify implications of imperfect integrations
- Interoperate between any kind of data structure

# Semantic Fabric



# Semantic Fabric





# Semantic Data Interoperability

Enabled by Categorical Mathematics