Trinity Graph Engine

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# Why do we need a graph system?

Existing Systems

- Mature data processing systems
  - RDBMS
  - Map Reduce Systems, e.g. cosmos

- Systems specialized for certain graph operations:
  - PageRank

Graph Data is "Special" …

- Random access (Poor Locality)
  - For a node, its adjacent nodes' content cannot be accessed without "jumping" no matter how you represent a graph
  - Not cache-friendly, data reuse is hard

- Unstructured nature of graph
  - Difficult to extract parallelism by partitioning data
  - Hard to get an efficient "Divide and Conquer" solution
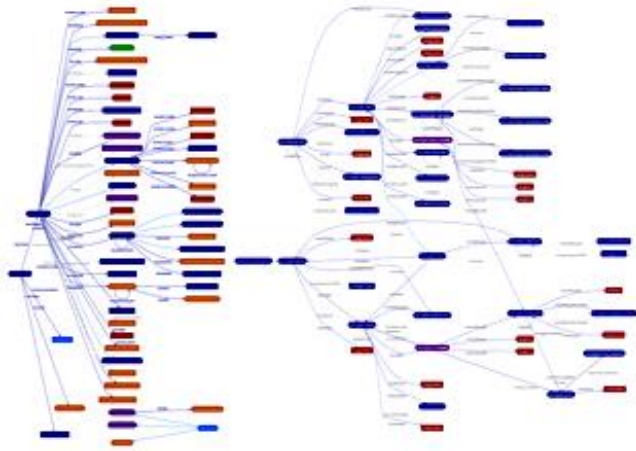
Graph in the Jail of Storage

- RDBMS/cosmos, mature but not for graphs

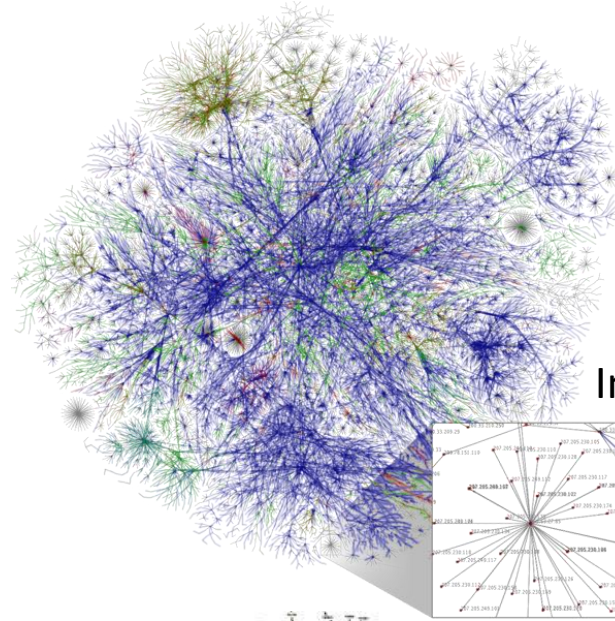- The commonest graph operation "traversal" incurs excessive amount of table joins
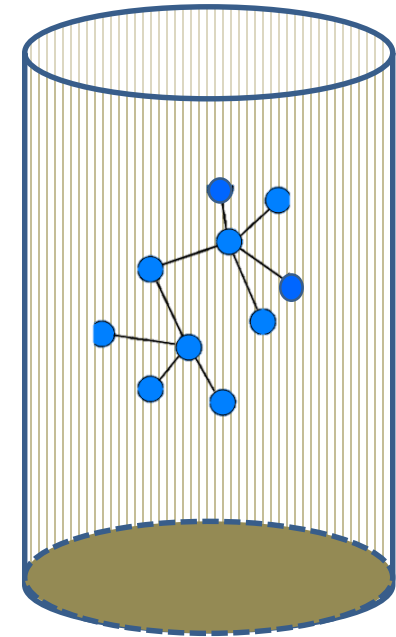
**Graph in the
Jail of the storage**
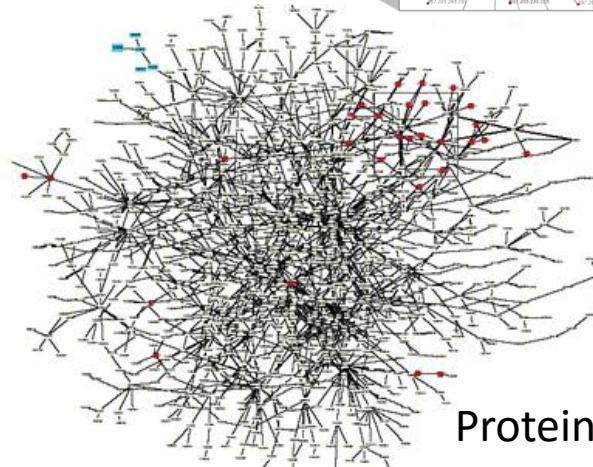
Challenge I: Diversity of Graphs

Satori Schema Graph

Internet Web Graph

Social Network

Protein Interaction Network
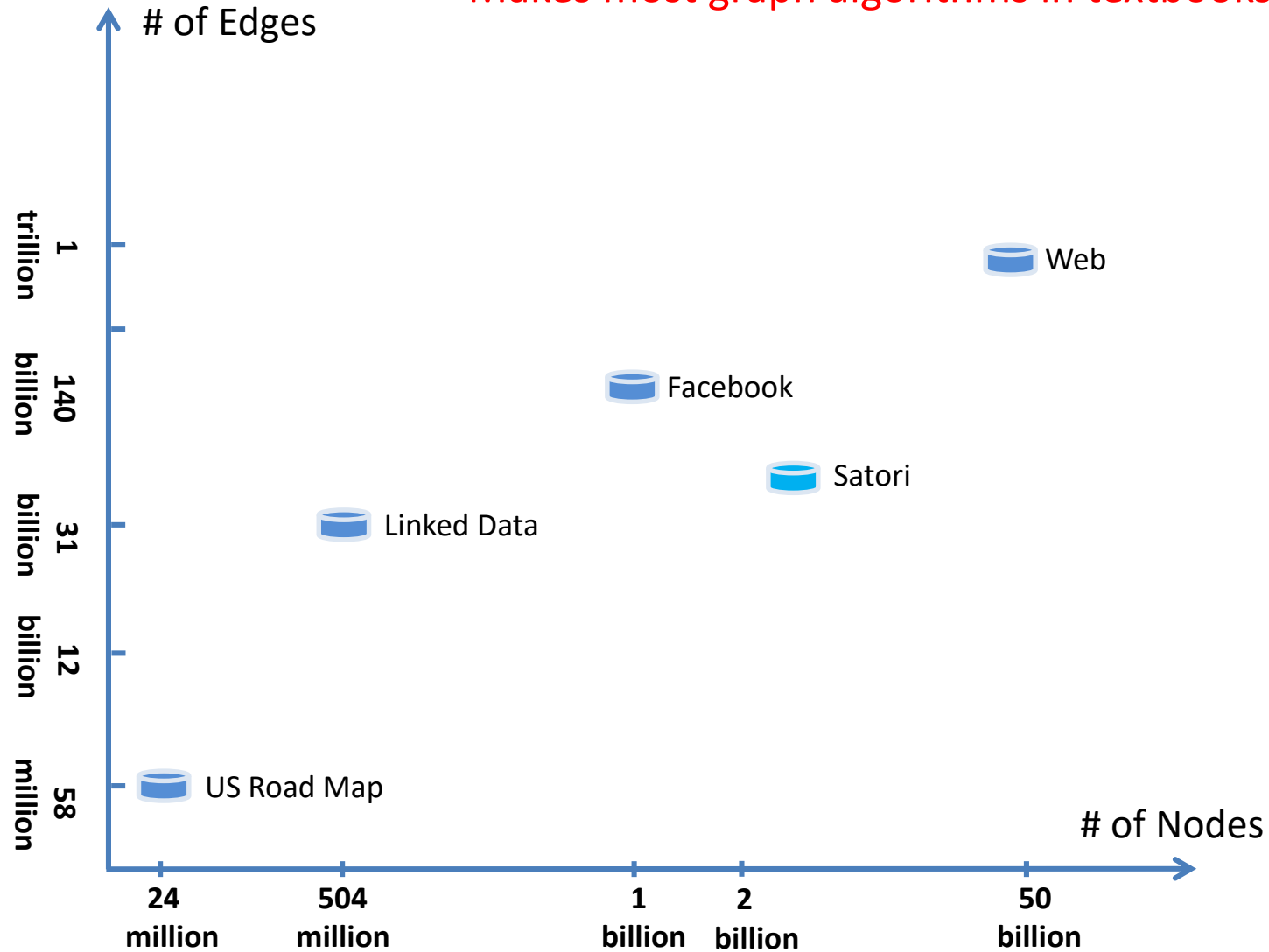
Do we need to design algorithms for each type of graphs❓

Challenge II: Diversity of Computations

- Online query processing
  - Shortest path query
  - Subgraph matching query
  - SPARQL query
  - …
- Offline graph analytics
  - PageRank
  - Community detection
  - …
- Other graph operations
  - Graph generation, visualization, interactive exploration, etc.
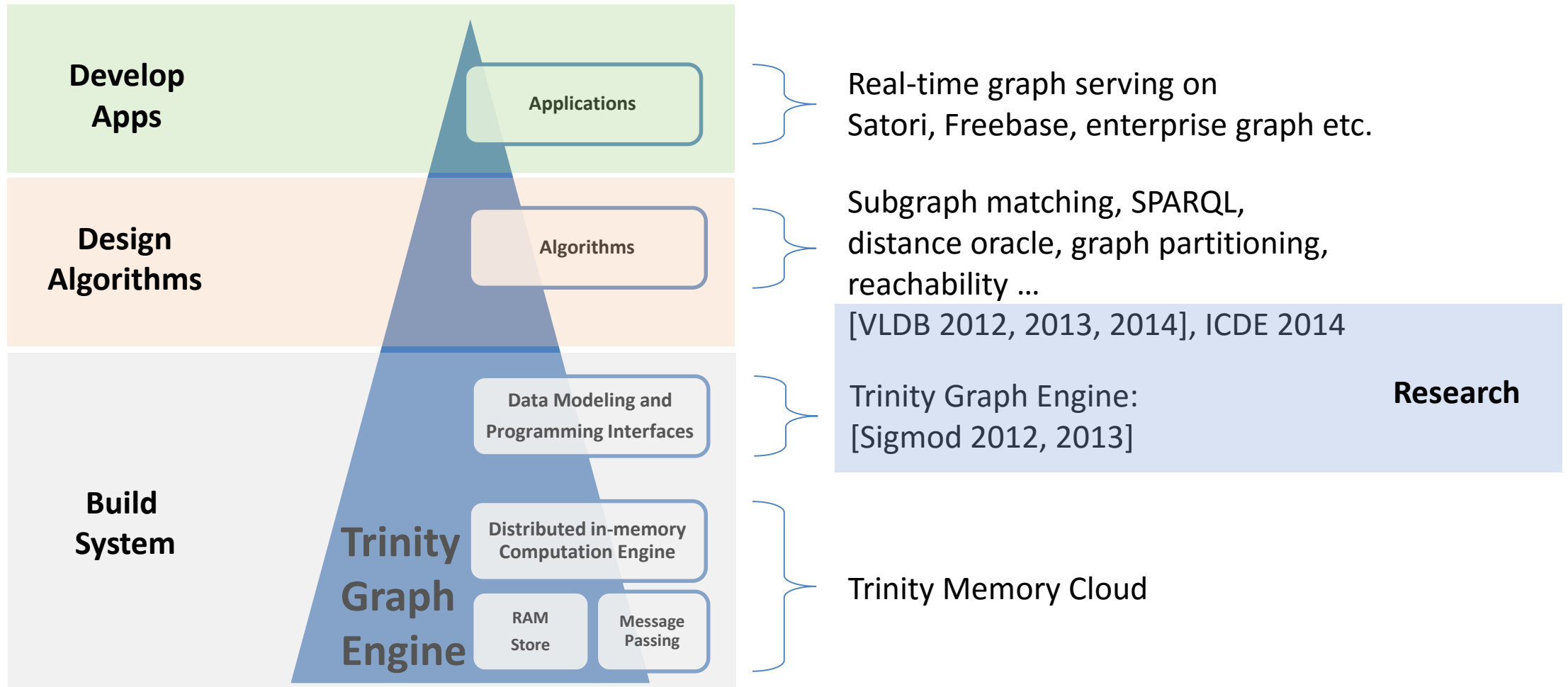
Do we need to implement systems for each graph operation**?**

Challenge III: The **Scale** of Graphs

Makes most graph algorithms in textbooks ineffective!

# of Edges

# of Nodes

1 trillion	Web
140 billion	Facebook
31 billion	Satori
12 billion	Linked Data
58 million	US Road Map

24 million   504 million   1 billion   2 billion   50 billion

Roadmap of the Graph Engine project

Develop Apps

Applications

Real-time graph serving on Satori, Freebase, enterprise graph etc.

Design Algorithms

Algorithms

Subgraph matching, SPARQL, distance oracle, graph partitioning, reachability ...
[VLDB 2012, 2013, 2014], ICDE 2014

Build System

Trinity Graph Engine

Data Modeling and Programming Interfaces

Trinity Graph Engine: [Sigmod 2012, 2013]

Research

Distributed in-memory Computation Engine

RAM Store

Message Passing

Trinity Memory Cloud

Design Philosophy

Not a one-size-fits-all graph system, but a graph engine

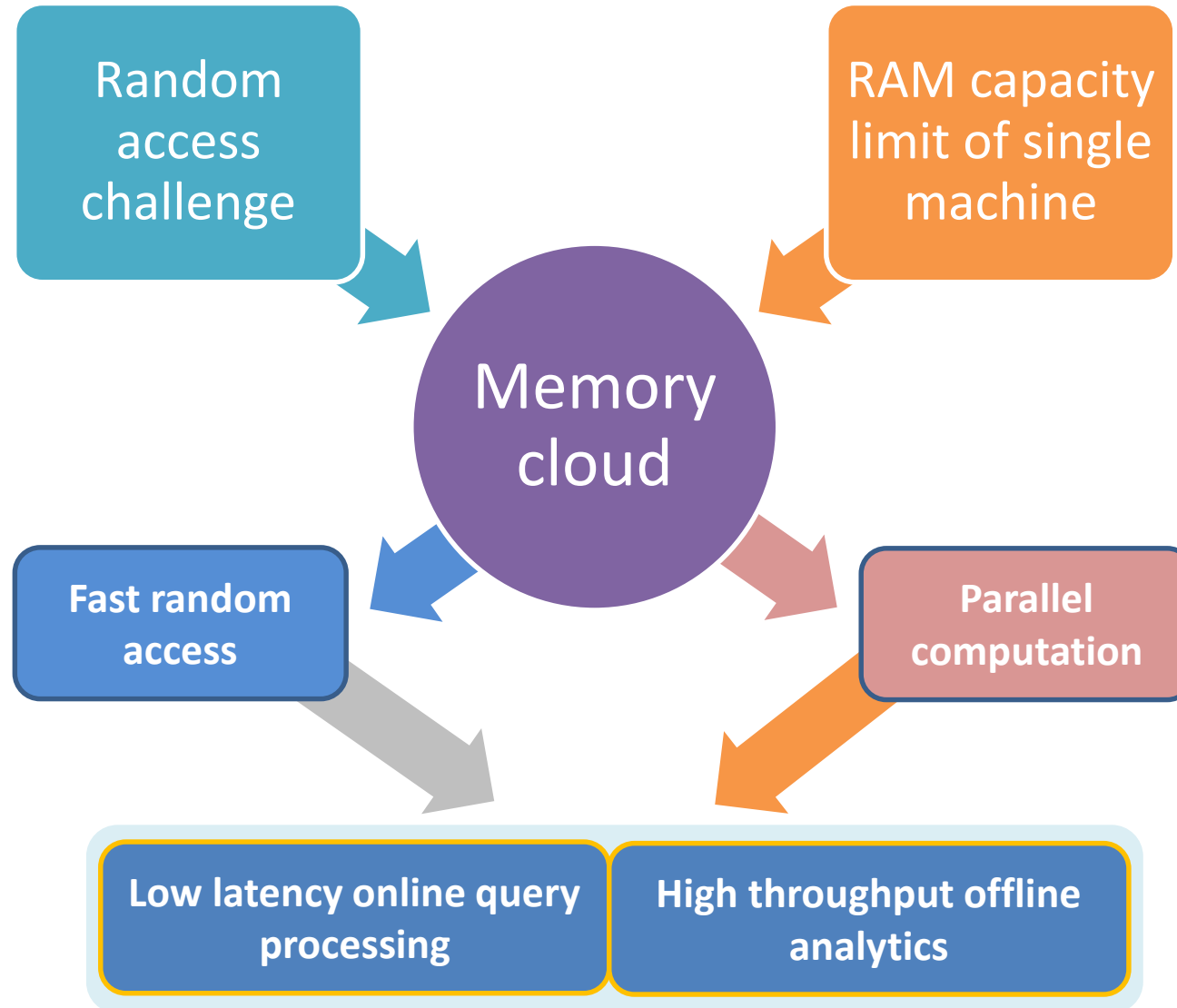Flexible data and computation modeling capability
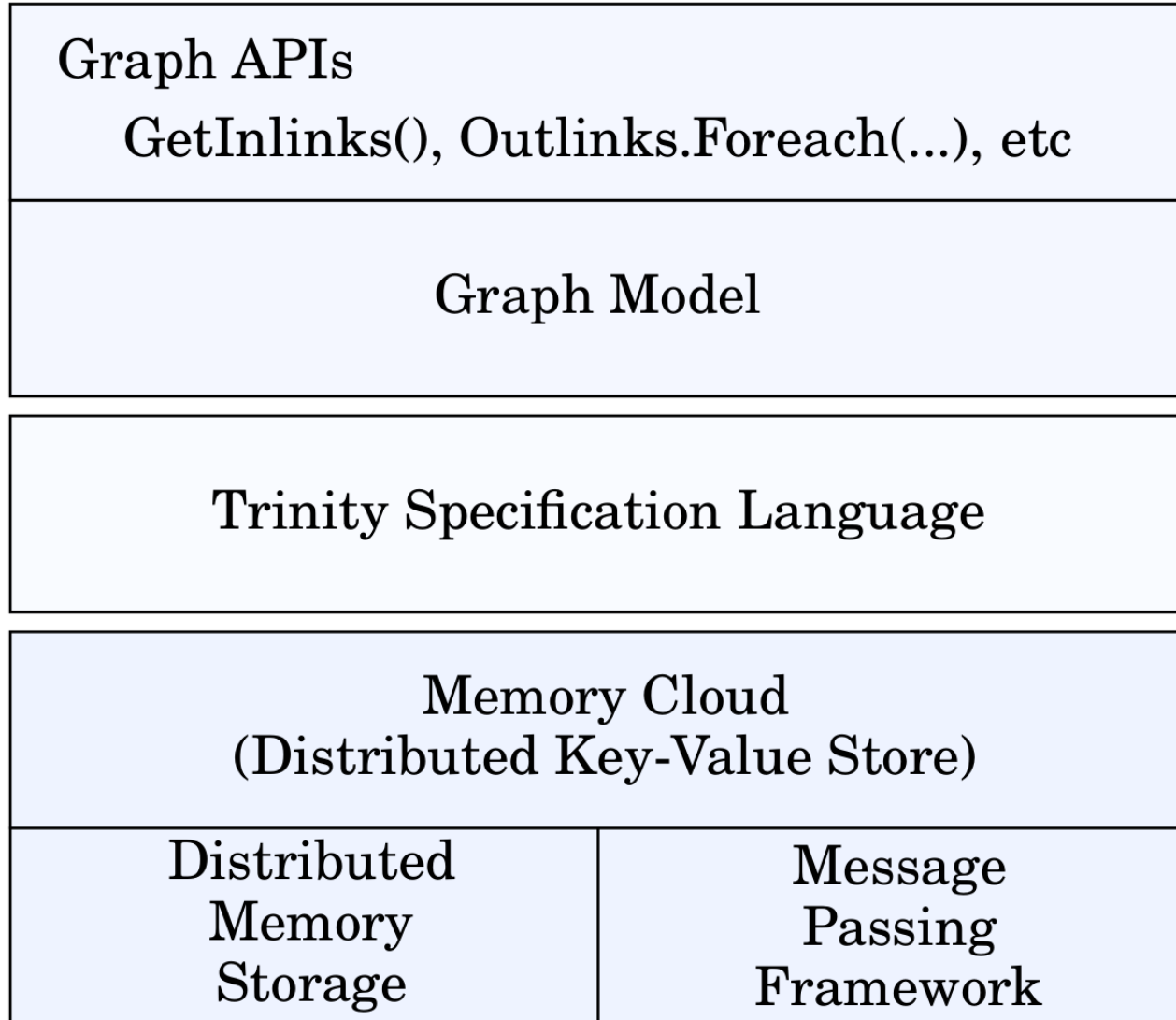
⬇

Trinity can morph into

a large variety of graph processing systems

Trinity = **Graph Modeling Tools +**
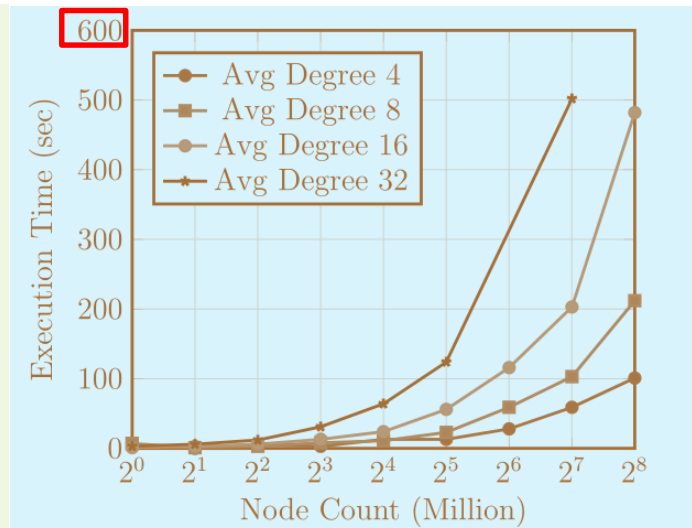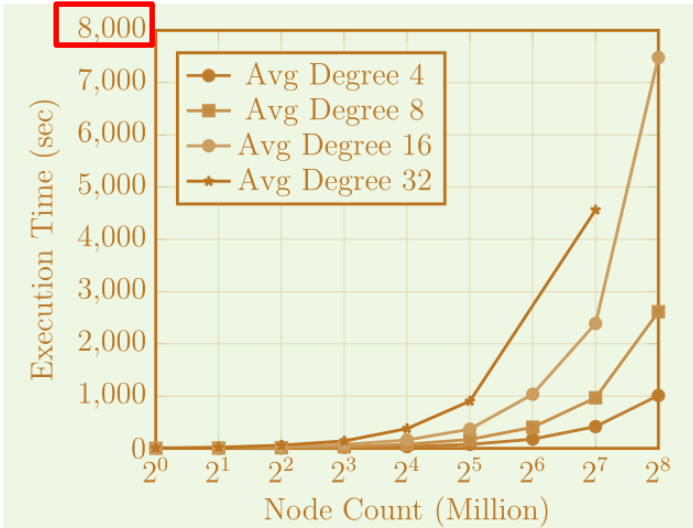**Distributed In-memory Data Store +**
Declarative Programming Model

Design Rationale of Memory Cloud

System Stack

Graph APIs   GetInlinks(), Outlinks.Foreach(...), etc
Graph Model
Trinity Specification Language
Memory Cloud (Distributed Key-Value Store)

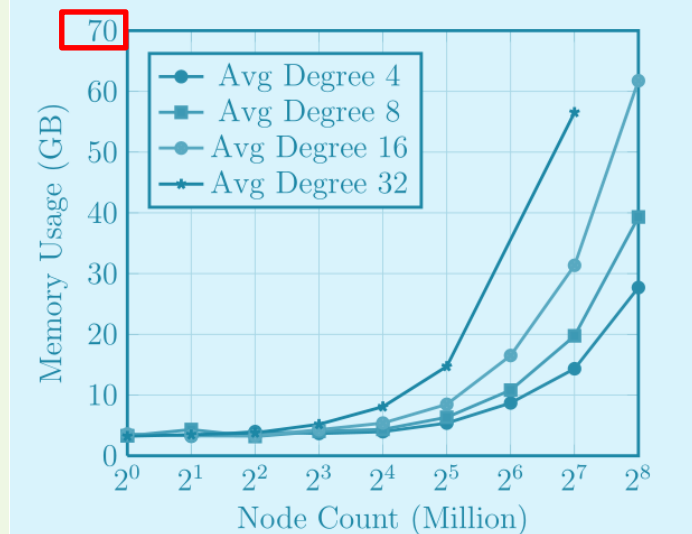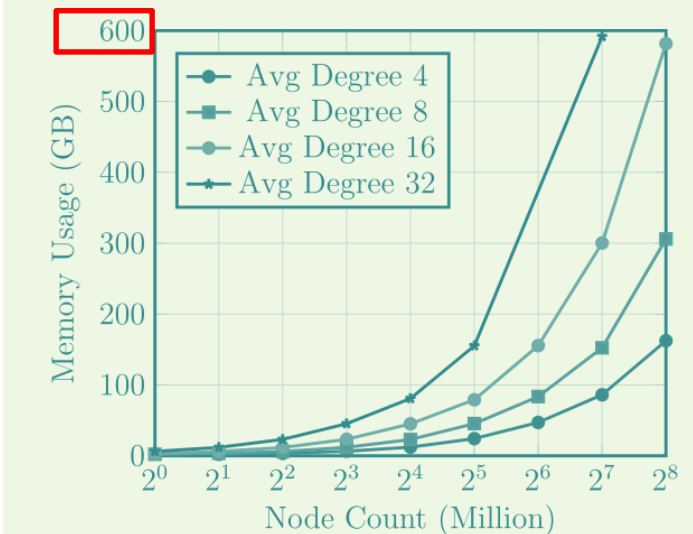| Distributed Memory Storage	Message Passing Framework

One Byte Counts
(Trinity vs. PBGL)
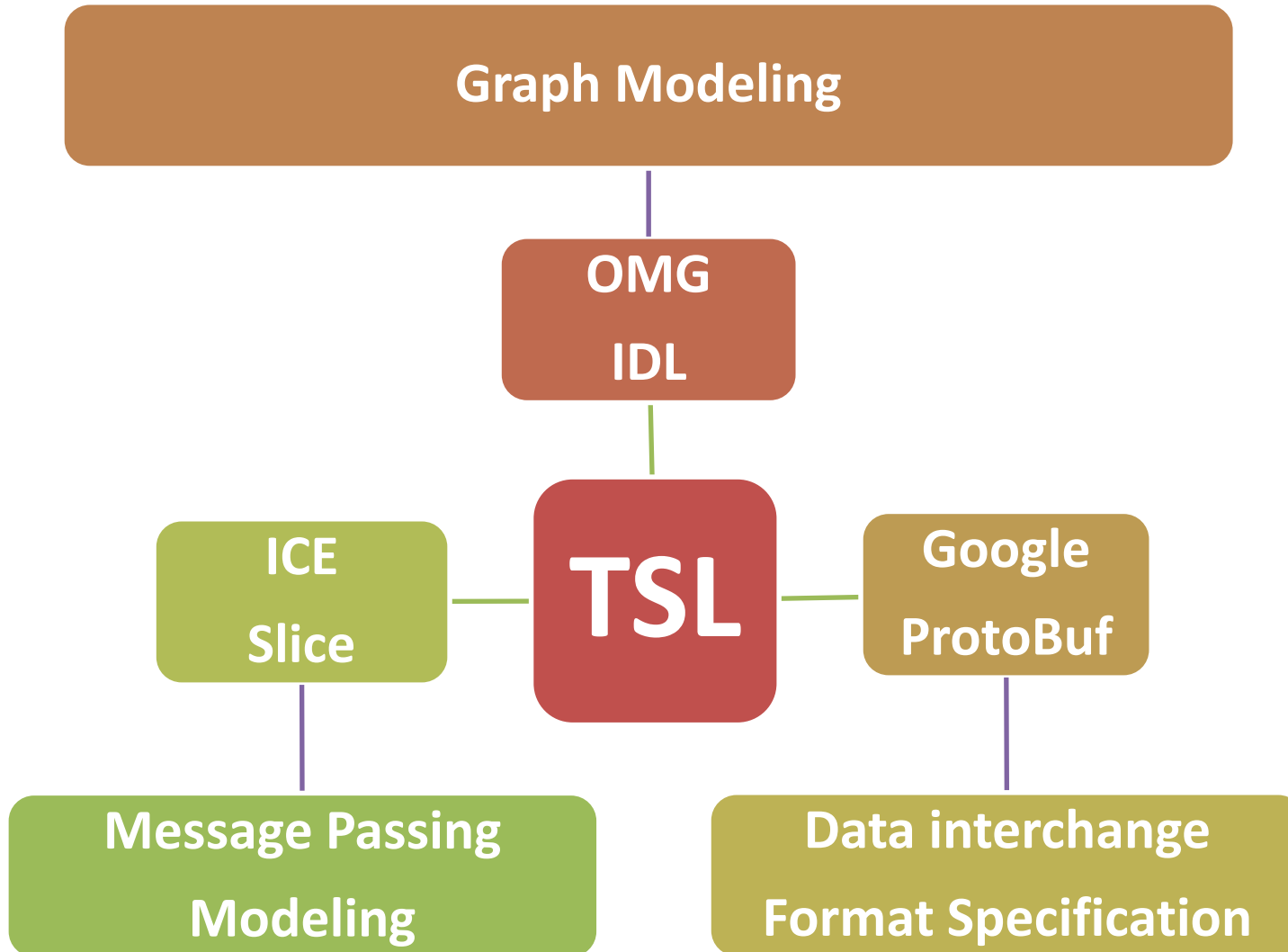

Execution Time

Memory Usage

PGBL

Trinity

Trinity Specification Language

Why TSL?

- TSL allows users to define graph schemata, and communication protocols through declarative interfaces.

- TSL makes Trinity memory cloud beyond a key-value store
  - Users are allowed to freely define the data schema
  - TSL makes message passing programming ever so easy
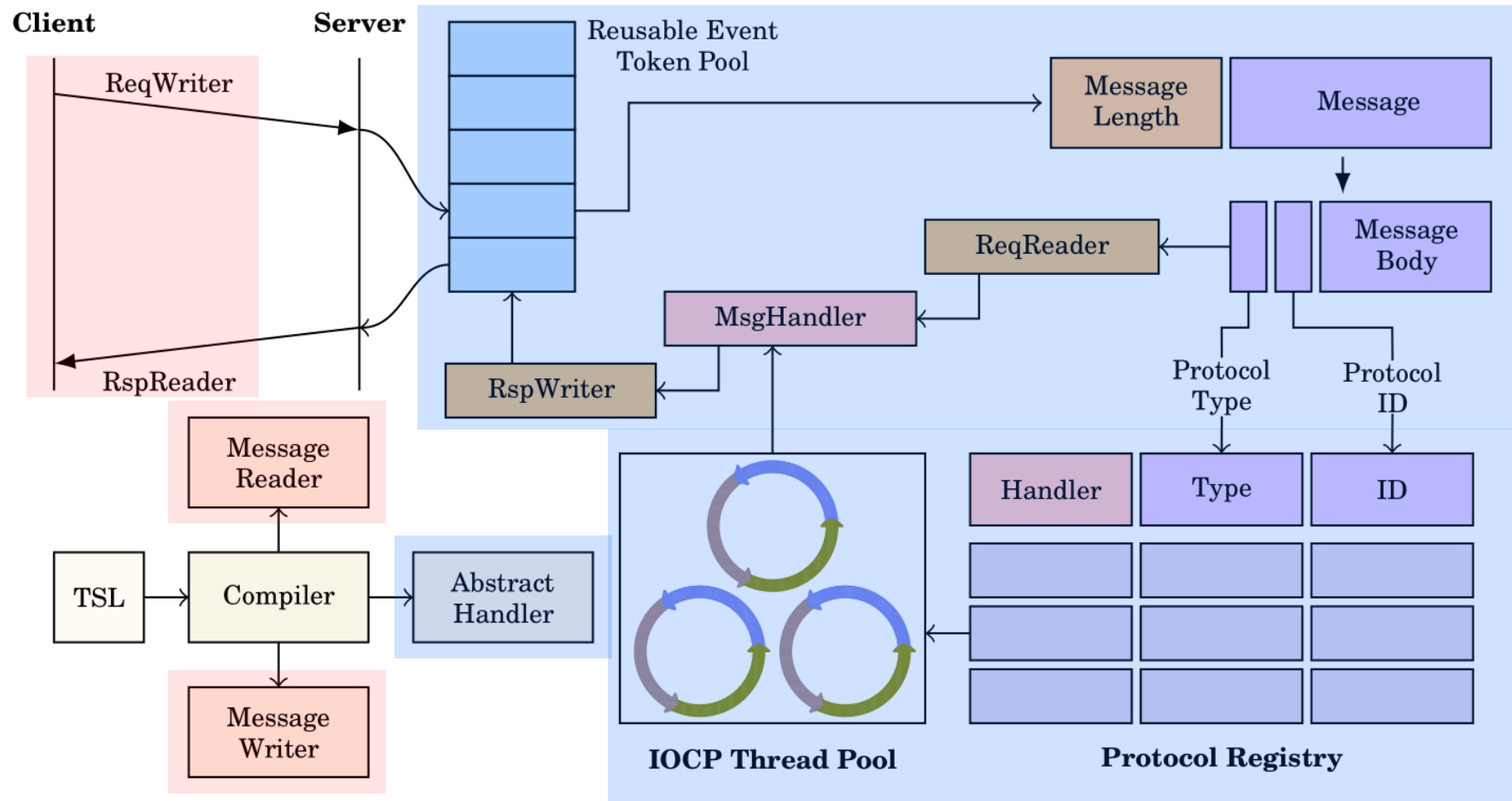
Modeling a Movie and Actor Graph

```
cell struct Movie
{
    string Name;
    [GraphEdge]
    List<CellId> Actors;
}


cell struct Actor
{
    string Name;
    [GraphEdge]
    List<CellId> Movies;
}
```

TSL-enabled Cell Accessor:
Efficient and User-friendly

Modeling Message Passing

```
struct MyMessage
{
    string Text;
}
protocol Echo
{
    Type: Syn;
    Request: MyMessage;
    Response: MyMessage;
}
```

TSL-Powered Message Passing

Trinity-enabled Graph Computation Paradigms

- **Vertex-centric graph analytics**
  – Prosperous since Pregel, e.g. Giraph, GraphChi

- **Approximate graph computation based on local sampling**
  – Enabled by randomly partitioned in-memory graph
  – Fast approximate computation with minimum communication costs
  – Application: distance oracle [VLDB 2014]

- **Index-free real-time online query processing**
  – Enabled by fast in-memory distributed graph exploration
  – Examples, subgraph match (vldb 2012) and Trinity.RDF (vldb 2013)

Query Index Examples

Algorithms	Index Size	Index Time	Update Cost
Ullmann [Ullmann76], VF2 [CordellaFSV04]	-	-	-
RDF-3X [NeumannW10]	$O(m)$	$O(m)$	$O(d)$
BitMat [AtreCZH10]	$O(m)$	$O(m)$	$O(m)$
Subdue [HolderCD94]	-	Exponential	$O(m)$
SpiderMine [ZhuQLYHY11]	-	Exponential	$O(m)$
R-Join [ChengYDYW08]	$O(nm^{1/2})$	$O(n^4)$	$O(n)$
Distance-Join [ZouCO09]	$O(nm^{1/2})$	$O(n^4)$	$O(n)$
GraphQL [HeS08]	$O(m + nd^r)$	$O(m + nd^r)$	$O(d^r)$
Zhao [ZhaoH10]	$O(nd^r)$	$O(nd^r)$	$O(d^L)$
GADDI [ZhangLY09]	$O(nd^L)$	$O(nd^L)$	$O(d^L)$

Index-based subgraph matching [Sun VLDB 2012]

Query Index Examples

Algorithms	Index Size for Facebook	Index Time for Facebook	Query Time on Facebook (s)
Ullmann [Ullmann76], VF2 [CordellaFSV04]	-	-	>1000
RDF-3X [NeumannW10]	1T	>20 days	>48
BitMat [AtreCZH10]	2.4T	>20 days	>269
Subdue [HolderCD94]	-	> 67 years	-
SpiderMine [ZhuQLYHY11]	-	> 3 years	-
R-Join [ChengYDYW08]	>175T	$> 10^{15}$ years	>200
Distance-Join [ZouCO09]	>175T	$> 10^{15}$ years	>4000
GraphQL [HeS08]	>13T$(r=2)$	> 600 years	>2000
Zhao [ZhaoH10]	>12T$(r=2)$	> 600 years	>600
GADDI [ZhangLY09]	$> 2 \times 10^5$T $(L=4)$	$> 4 \times 10^5$ years	>400

Index-based subgraph matching [Sun VLDB 2012]

Index-free Query Processing
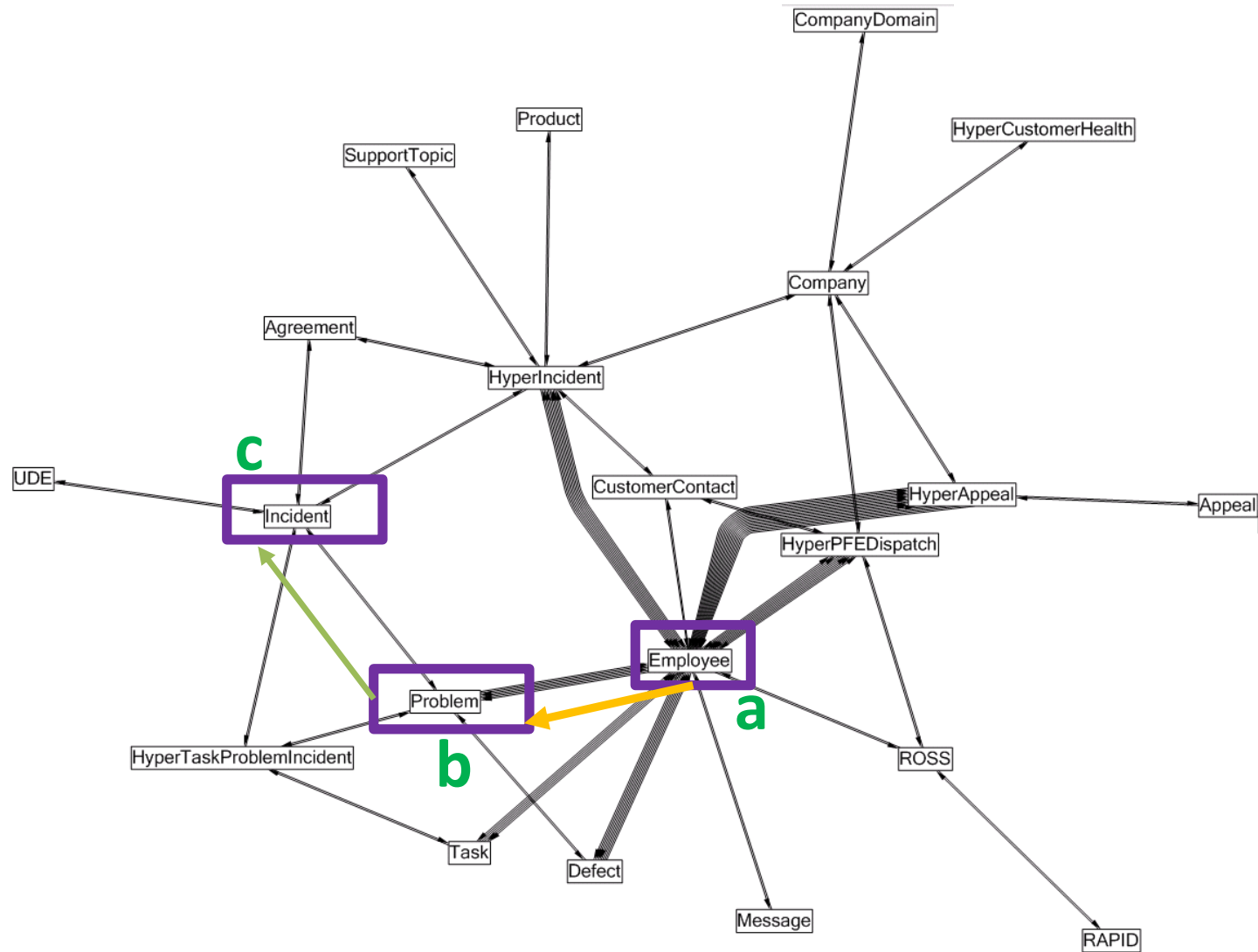
Trinity Applications

Source Code Graph (Visual Studio)

Source Code Graph (Visual Studio)

ACADEMIC SERACH

Demo   Example

```
FROM a in {"Author.FullName='Leslie Lamport'"} MATCH a-->b(PaperAuthorOrganization)-->c(Paper) SELECT a.FullName,c.Title
```

Search   STOP

Query Result

a.FullName	c.Title
Leslie Lamport	Composition: A Way to Make Proofs Harder
Leslie Lamport	A Formal Basis for the Specification of Concurrent Systems
Leslie Lamport	The Operators of TLAC
Leslie Lamport	The Synchronization of Independent Processes
Leslie Lamport	Corrigendum: "A New Approach to Proving the Correctness of Multiprocess Programs"
Leslie Lamport	Comment on Bell's quadratic quotient method for hash coded searching
Leslie Lamport	SIFT: Design and analysis of a fault-tolerant computer for aircraft control
Leslie Lamport	Latex: a document preparation system
Leslie Lamport	Constructing digital signatures from a one-v~ray function
Leslie Lamport	Specifying

1 2 3 4 5 6 7 8 9 10 … >>

Knowledge Graph
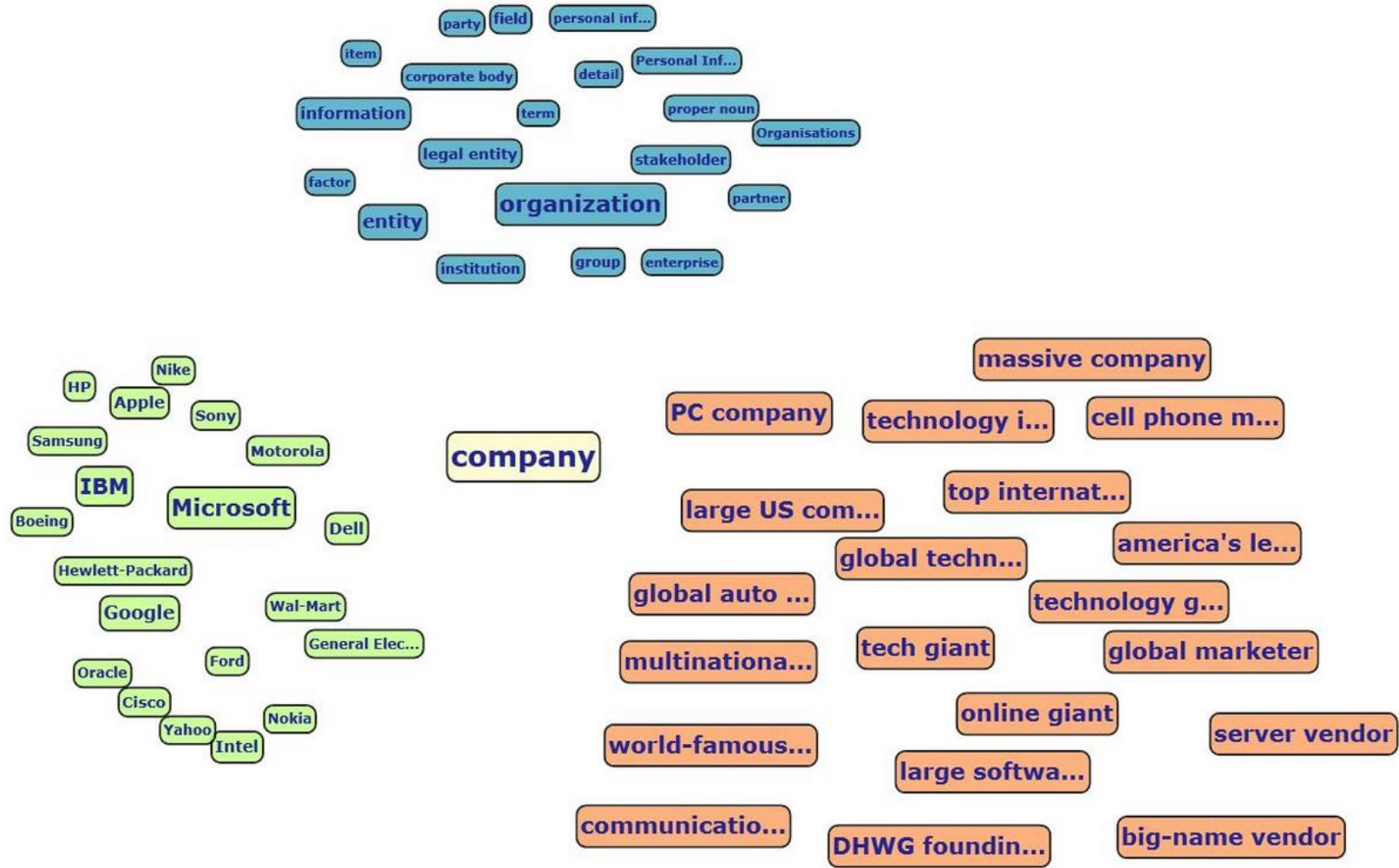
Satori Knowledge Graph
Powered by Trinity

Challenges of Serving Satori

Satori: An ever-growing knowledge repository	
Raw RDF data	4T+
Entities	2.4B+
Triple Facts	20B+

- Complex data schema
  - Rich relations
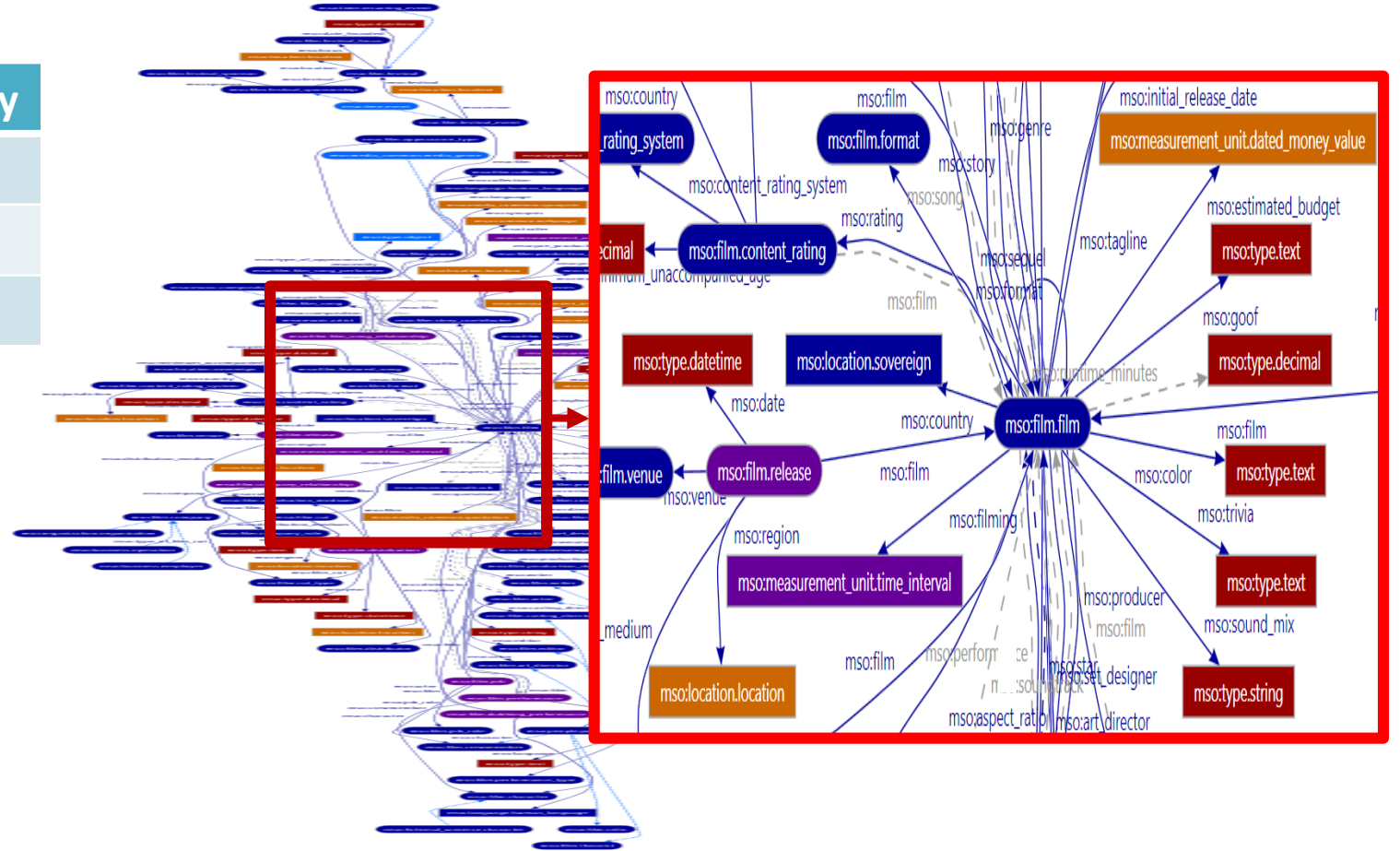
Challenges of Serving Satori

Satori: An ever-growing knowledge repository	
Raw RDF data	4T+
Entities	2.4B+
Triple Facts	20B+

- Complex data schema
  - Rich relations
  - Multi-typed entities

123 mso/type.object.name "Pal"

*123 mso/type.object.type
mso/organism.dog*
123 mso/organism.dog.breeds "Collie Rough"

123 mso/type.object.type mso/film.actor
123 mso/film.actor.film 789
789 mso/type.object.type mso/film.film
789 mso/type.object.name "Lassie Come Home"

as a dog

as an actor

"Pal"

Challenges of Serving Satori

SATORI

Satori: An ever-growing knowledge repository	
Raw RDF data	4T+
Entities	2.4B+
Triple Facts	20B+

- Complex data schema
  - Rich relations
  - Multi-typed entities
- Distributed in-memory knowledge graph

Knowledge Serving Services/APIs

director

film

Distributed In-memory Graph

actor

Trinity Graph Engine

External Storage
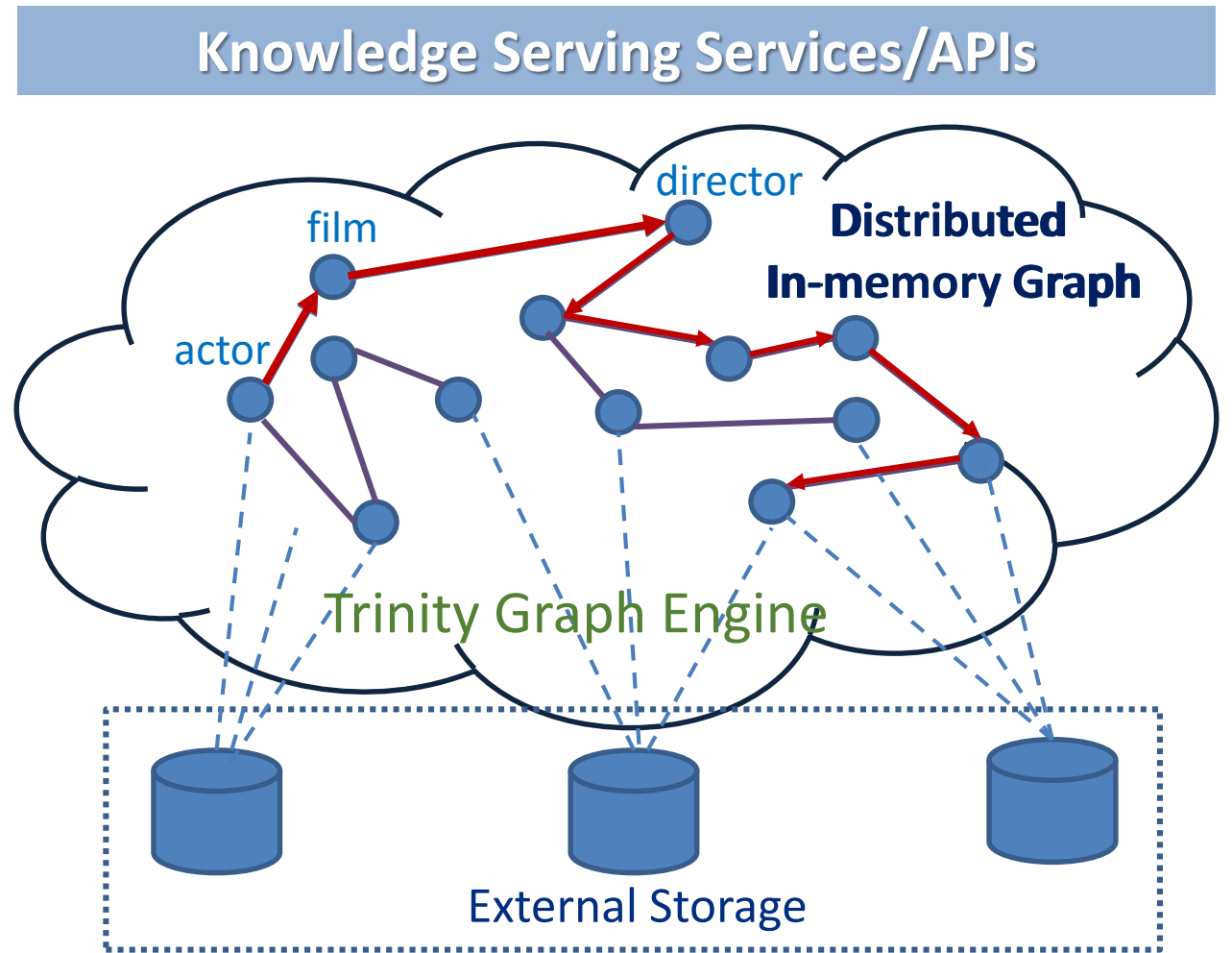
Satori in Native Graph Database for Real-time Knowledge Serving

Challenges of Serving Satori

Satori: An ever-growing knowledge repository	
Raw RDF data	4T+
Entities	2.4B+
Triple Facts	20B+

- Complex data schema
  - Rich relations
  - Multi-typed entities

ID	436234
Name	"Lassie Come Home"
Types	Film

ID	143422
Name	"Pal"
Types	Dog, Actor

Perform	436234

Breeds	"Collie Rough"
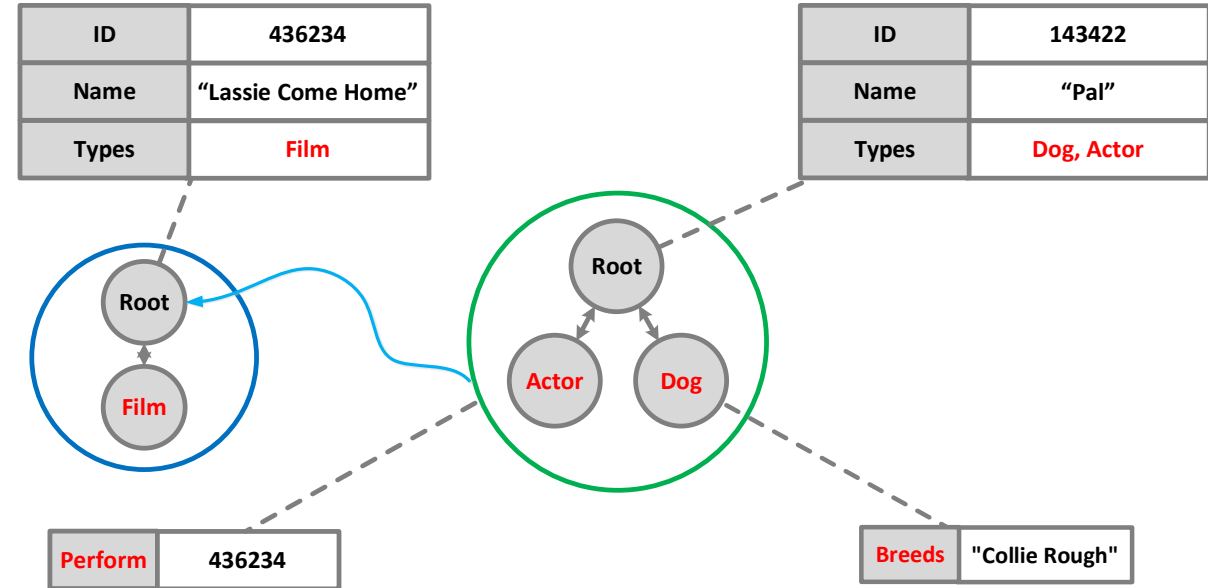
Modeling Multi-Typed Satori Entities in a Strongly Typed Manner

Trinity's Storage Architecture for Satori
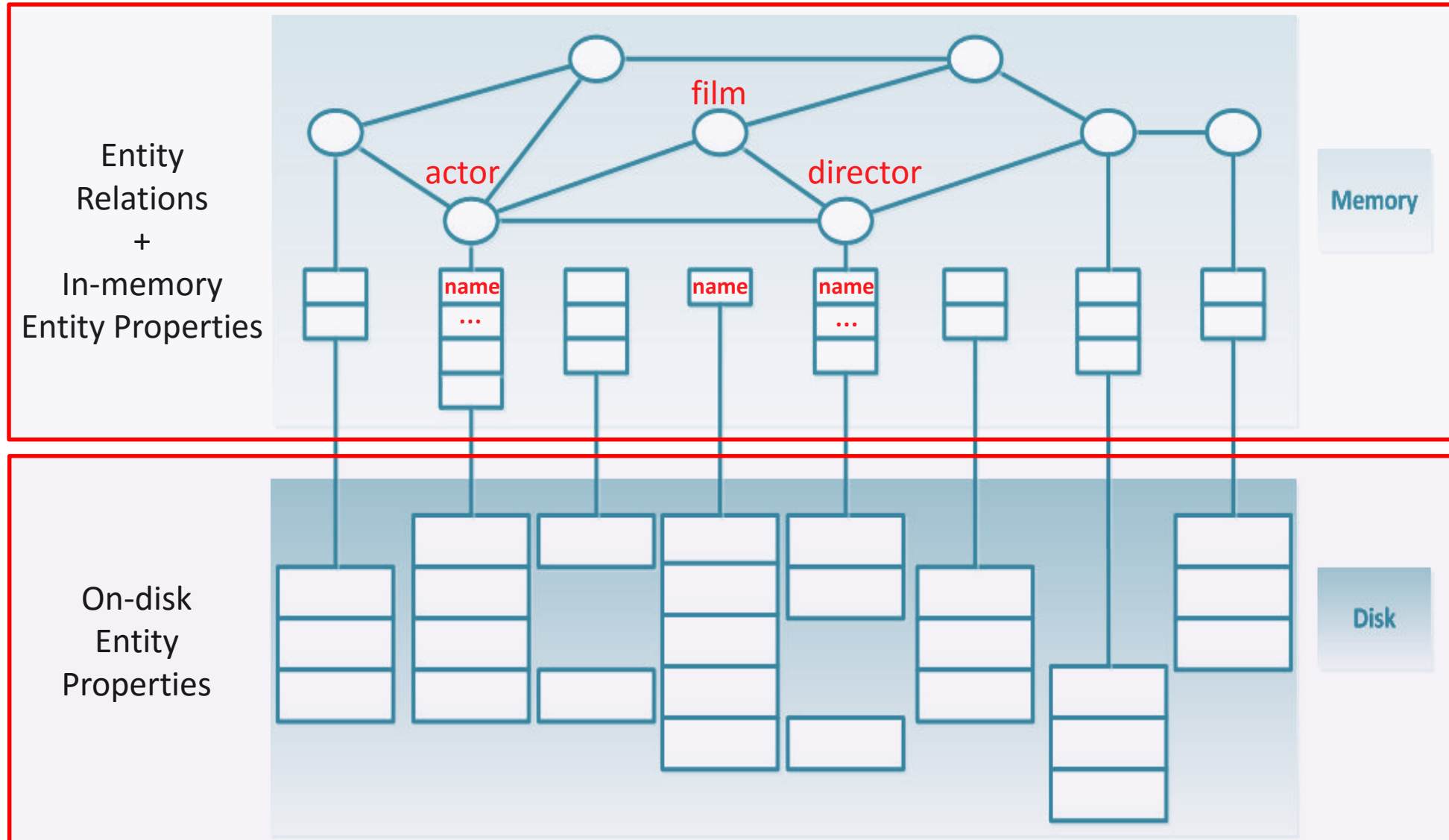
Demo

SATORI

bill gate

Search

bill gate

bill gatekeeper

bill gately

bill gatens

bill gates

bill gates bill

bill gates jnr

Satori Service Portal

Satori

[   ]   **Search**

Harvard University

award.presenting_organization,   award.ranked_item,   award.winner,   book.author,
education.academic_institution,   education.educational_institution ...

Harvard University

organization.organization,   type.object

harvard university

internet.social_network_user,   people.person,   type.object

harvard university

internet.social_network_user,   people.person,   type.object

Harvard University

local.entity,   type.object

Harvard University

local.entity,   type.object

Prev Page   Next Page

Harvard University

Harvard University is an American private Ivy League
research university located in Cambridge, Massachusetts,
United States, established in 1636 by the Massachusetts
legislature. Harvard is the oldest institution of higher
learning in the United States and the first corporation
(officially The President and Fellows of Harvard College)
chartered in the country. Harvard's history, influence,...

Types

award.presenting_organization,   award.ranked_item,   award.winner,
book.author,   education.academic_institution,
education.educational_institution ...

Predicates

education.educational_institution.total_enrollment

education.educational_institution.color

education.educational_institution.subsidiary_or_constituent_schools

education.educational_institution.number_of_staff

education.educational_institution.honorary_degrees_awarded

education.educational_institution.school_sports_team

Prev Page   Next Page

Values

"Harvard Extension School"

"Harvard Medical School"

"Harvard Business School"

"Harvard College"

"Harvard Division of Continuing Education"

"John F. Kennedy School of Government"

Prev Page   Next Page

Entity Explorer

Schema Graph

Meta Graph of Satori

Schema Type:

Schema Path:

mso/people.person `[ Go ]`

mso/people.person `---▶` mso/book.author `[ Go ]`

Fields:

.bust_measurement	mso/type.decimal
.date_of_birth	mso/type.datetime
.eye_color	mso/type.text
.first_name	mso/type.string
.hair_color	mso/type.text
.height	mso/type.decimal
.hips_measurement	mso/type.decimal
.last_name	mso/type.string
.waist_measurement	mso/type.decimal
.weight	mso/type.decimal

Links:

.business_employment_tenure	mso/business.employment_tenure
.children	mso/people.person
.city_of_birth	mso/location.location

mso/people.person	.quotation	mso/media_common.quotation
mso/media_common.quotation	.character	mso/fictional_universe.character
mso/fictional_universe.character	.appears_in_these_fictional_universes	mso/fictional_universe.universe
mso/fictional_universe.universe	.literary_series	mso/book.literary_series
mso/book.literary_series	.author	mso/book.author

Schema Graph Services

Knowledge Graph API   Schema Graph API   Auto Completion API

Satori Knowledge Graph Access API

API Names	Availability	Description
GetEntityIdByName	Available	Gets a list of Trinity entity Ids by the specified entity name.
GetPredicatesByEntityId	Available	Gets a list of predicates for the entity with the specified Trinity entity Id.
GetValuesByEntityPredicate	Available	Gets the values of the specified predicates for the specified entity.
GetSubjectsByPredicateObject	Available	Gets the subjects for the given object and a predicate.
GetEntityIdBySatoriId	Available	Gets the corresponding Trinity entity Id for the specified Satori Guid.
GetSatoriIdByEntityId	Available	Gets the corresponding Satori Guid for the specified Trinity entity Id.
GetRankedEntityIdByName	Available	Gets a list of Trinity entity Ids by the specified entity name sorted by their static rank.
GetScoredValuesByEntityPredicate	Available	Gets the values of the specified predicates for the specified entity, sorted by confidence score.
GetSortScoredValuesByEntityPredicate	Available	Gets the values of the specified predicates for the specified entity, sorted by the column index (1 for...
GetEntityDescription	Available	Gets the description of the specified entityid.

Testing: GetScoredValuesByEntityPredicate

Please input test parameters below:

EntityId   `24604518639751`

Predicate   `mso/film.actor.film`

Submit

PredicateValue	ConfidenceScore	OverallScore
2987469205879	0.71	1.311128
116281907553515	0.71	1.409593
265920831012309	0.71	1.416611
58184534540412	0.71	1.710736
237856925167352	0.71	1.228339
57628320423344	0.71	1.272193

▶

Page 1   of 1

Knowledge Serving APIs

Satori   film   [Add]

View   TQL   Results

Graphical Query Interface

v0 (film)

v2 (film_director)

v1 (film_actor)

▶
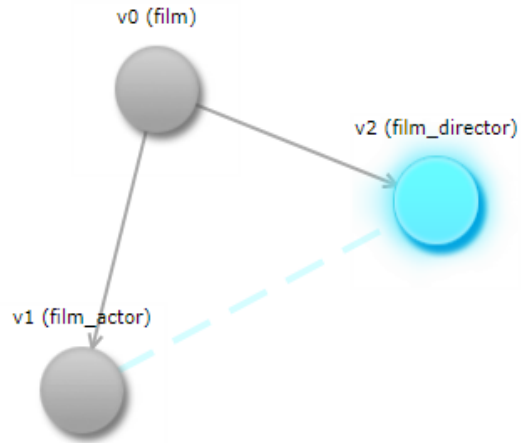
Node Information

Alias: v2
Type: film_director
URI: mso_film_director

Conditions:

Outputs:

Steve Saari
Steve Sacks
Steve Sale
Steve Salinaro
Steve Salisian
Steve Sanders
Steve Sanguedolce
Steve Saporito
Steve Savage
Steve Savitz
Steve Scheffler

▼

You could add some conditions a

| name ▼ | = ▼ | Steve S |

◀   Submit   ▶

Powered By Trinity Graph Engine
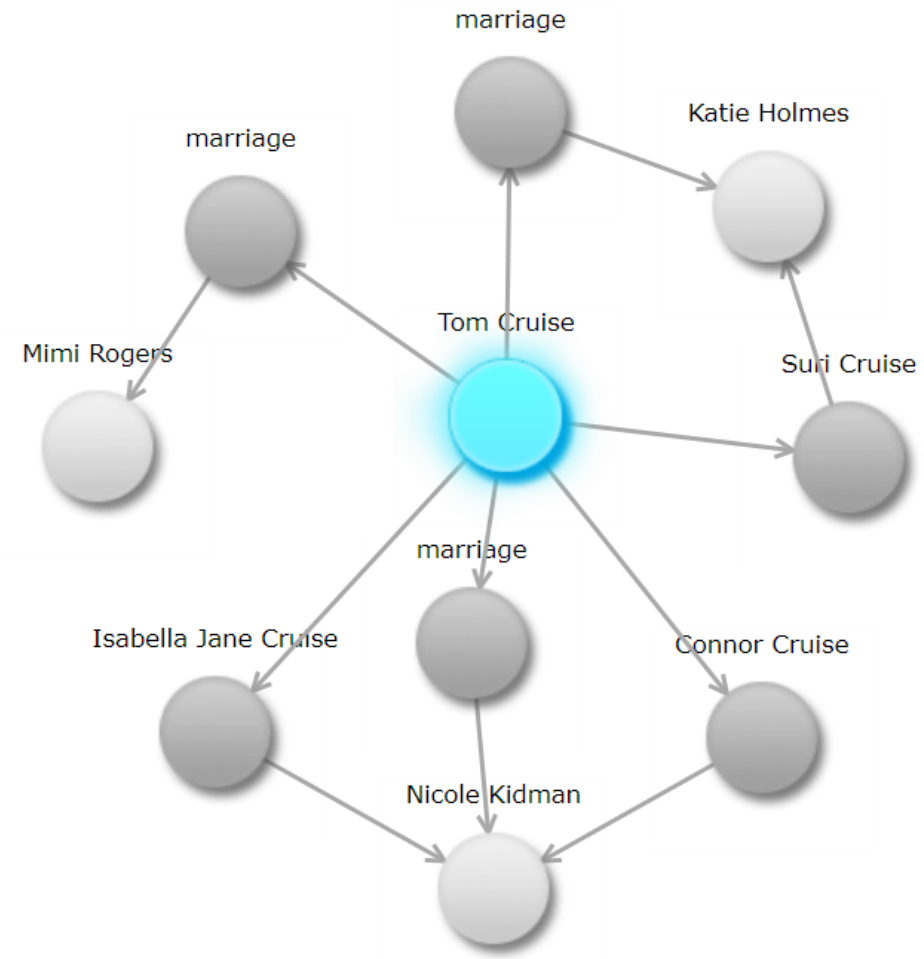
Add   Search

Tom Cruise, Mimi Rogers, Nicole Kidman, Katie Holmes

Results   View

Tom Cruise

Tom Cruise (born Thomas Cruise Mapother IV; July 3, 1962), is an American film actor and producer. He has been nominated for three Academy Awards and has won three Golden Globe Awards. He started his career at age 19 in the 1981 film Endless Love. After portraying supporting roles in Taps (1981) and The Outsiders (1983), his first leading role was in Risky Business, released in August 1983. Cruise became a full-fledged movie...

Types

award.nominee, award.winner, film.actor, film.director, film.producer, film.story_contributor ...

Relation Search

Thanks!

http://www.graphengine.io/