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Incremental View Maintenance over Array Data

Weijie Zhao[1], Florin Rusu[1,2],
Bin Dong[2], Kesheng Wu[2], Peter Nugent[2]

University of California, Merced[1]
Lawrence Berkeley National Laboratory[2]

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Outline

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Astronomical Catalogs

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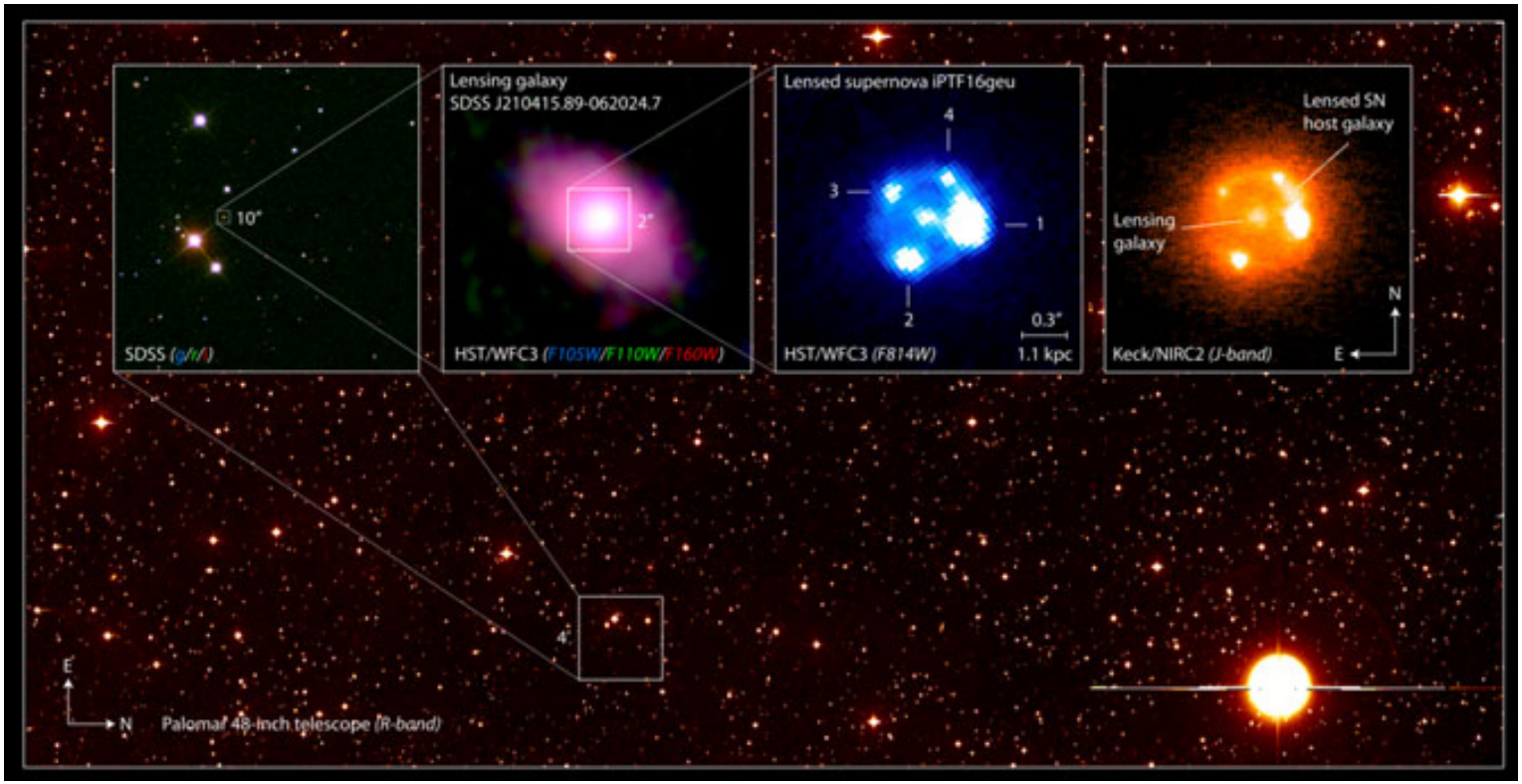
- Sloan Digital Sky Survey (SDSS), Palomar Transient Factory (PTF), etc.
- Transient identification: supernovae detection, exoplanet search



Array Construction

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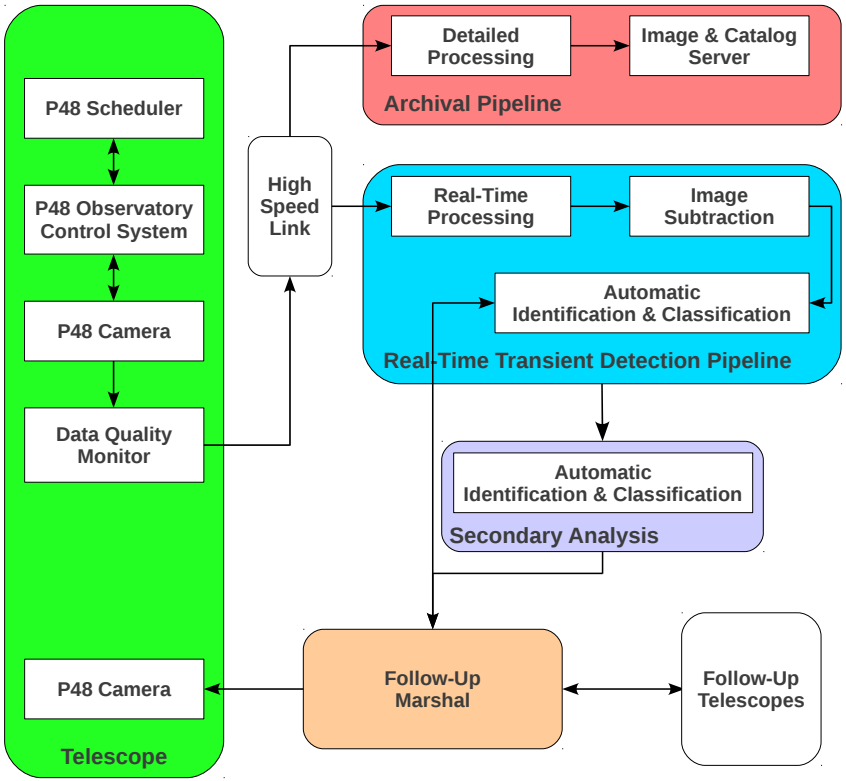

- Image $\xrightarrow{\textit{Image processing}}$ Objects $\rightarrow$ 3-D array [`ra, dec, time`]

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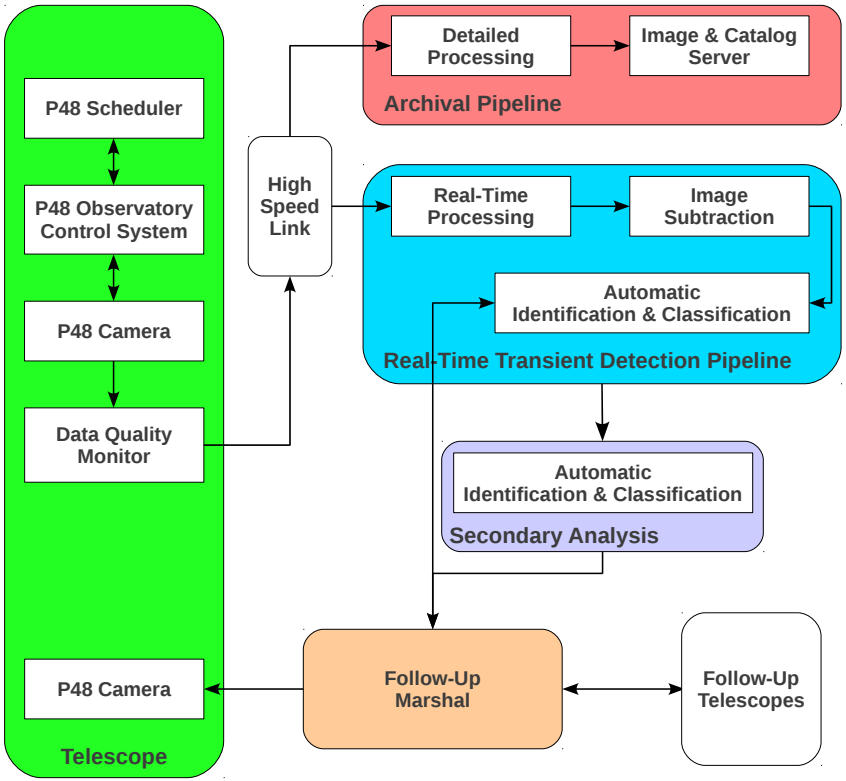

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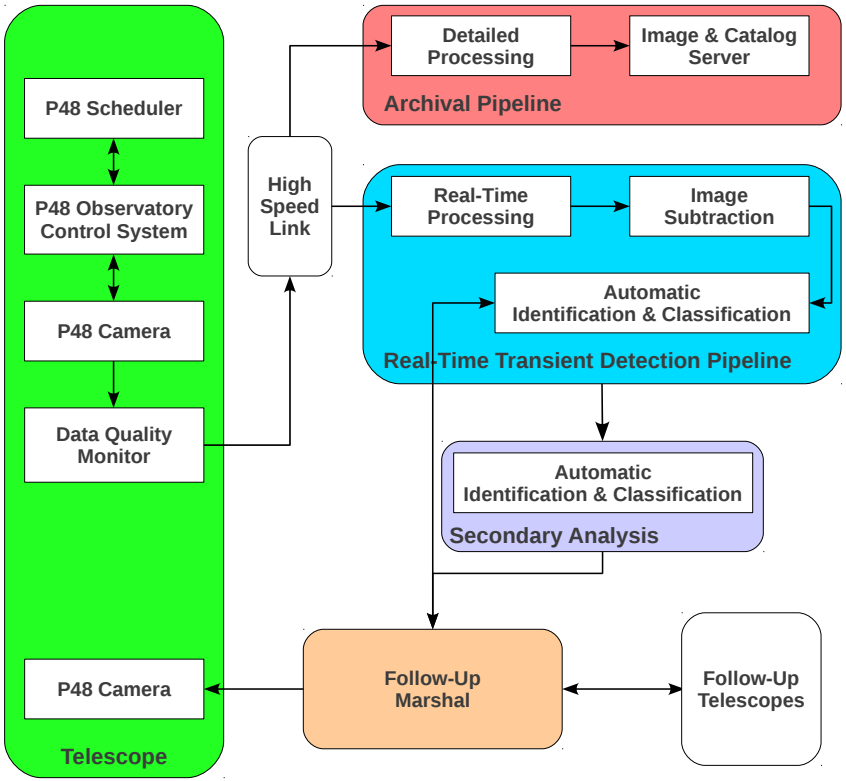

- Image $\xrightarrow{\textit{Image processing}}$ Objects $\rightarrow$ 3-D array [`ra, dec, time`]
- Array is chunked and stored in a shared-nothing array database
- Array is sparse and skewed

Astronomical Data Products

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- Gamma Ray Burst: extremely energetic explosions in distant galaxies that destroy everything around
  - For each dectection, all its neighbor detections are within 12 hours with increasing magnitude
- M-Dwarf Flares: periodic flares with period larger than a month
  - No two neighbor dectections within a month

Astronomical Data Products

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- Neighborhood matching $\rightarrow$ Array similarity join (expensive)
- Astronomical data products $\rightarrow$ Materialized query result

Astronomical Data Products

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- Neighborhood matching → Array similarity join (expensive)
- Astronomical data products → Materialized query result
- New detections every night → Base array updates
- Maintained data products → Incremental view maintenance over arrays

News Headline

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Rare Supernova Discovery Ushers in New Era for Cosmology

Berkeley Lab astrophysicists develop novel method for finding gravitationally lensed Type 1a supernovae

News Release Lir

'Major breakthrough' as supernova four billion light years from Earth is captured from four different angles in a stunning world first

- **Strange event occurred because light from the supernova bent through a galaxy**
- **Galaxies bend light through an effect that is called 'gravitational lensing'**
- **The galaxy magnified the supernova 50 times to give astronomers a unique view**
- **Supernovae are important to study as they reveal how the universe expands**

By HARRY PETTIT FOR MAILONLINE
PUBLISHED: 14:00 EDT, 20 April 2017 | **UPDATED:** 14:01 EDT, 20 April 2017

Astronomers Get Rare View Of Type Ia Supernova Magnified 50 Times

21 April 2017, 9:01 am EDT **By Luan Chan Tech Times**

Contributions

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- Model incremental array view maintenance as an optimization formulation – including adaptive array and view reorganization

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- Formal array view definition
- Model incremental array view maintenance as an optimization formulation – including adaptive array and view reorganization
- Propose an effective three-stage heuristics
- Introduce an analytical cost model for query integration
- Experimentally compare against existing solutions on PTF catalog and LinkedGeoData

Incremental Array View Maintenance Axes

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- Views over array similarity join (Zhao 2016)
  - Encompasses a larger variety of join predicates
  - Composable

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- Distributed processing (Luo 2003, Liu 2005)
  - Potential join pairs for each chunk are magnified
- Recursive maintenance (Ahmad 2012, Nikolic 2016)

Outline

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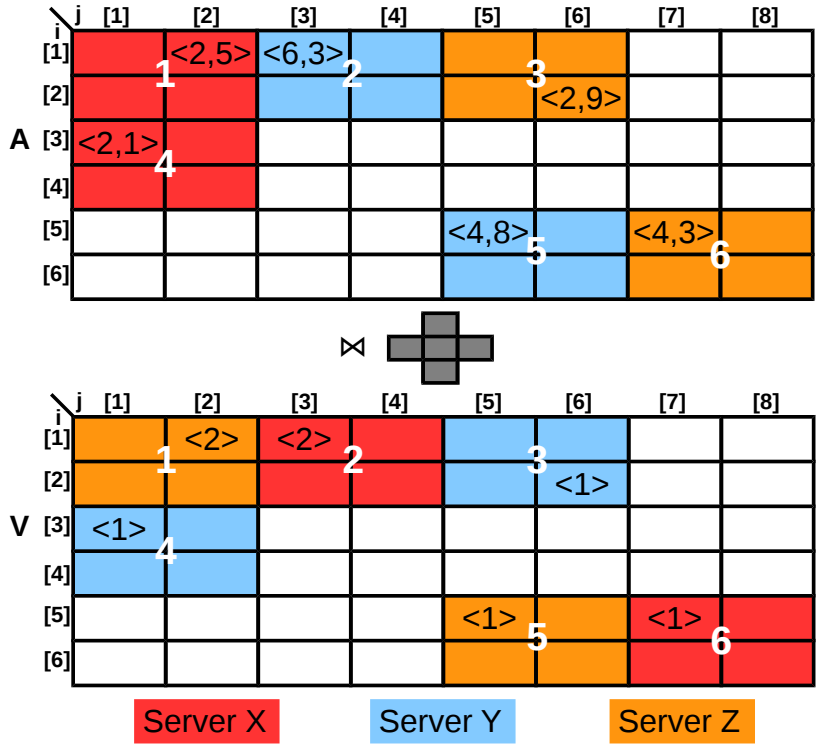
Array Data Model




```
CREATE ARRAY VIEW V AS
  SELECT COUNT(*) AS cnt
  FROM A A1 SIMILARITY JOIN A A2
       ON (A1.i = A2.i) AND (A1.j = A2.j)
       WITH SHAPE L1(1)
  GROUP BY A1.i, A1.j
```

Array View Definition

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n multi-dimensional arrays $\alpha_1, \ldots, \alpha_n$
k unary array operators $\oplus_1, \ldots, \oplus_k$
$$V \leftarrow\!\shortmid \oplus_1 \left(\cdots \oplus_k \left(\alpha_1 \bowtie^{\mathcal{M}_1}_{\sigma_1, f_1} \alpha_2 \bowtie^{\mathcal{M}_2}_{\sigma_2, f_2} \cdots \bowtie^{\mathcal{M}_{n-1}}_{\sigma_{n-1}, f_{n-1}} \alpha_n \right) \cdots \right)$$

For example:

```
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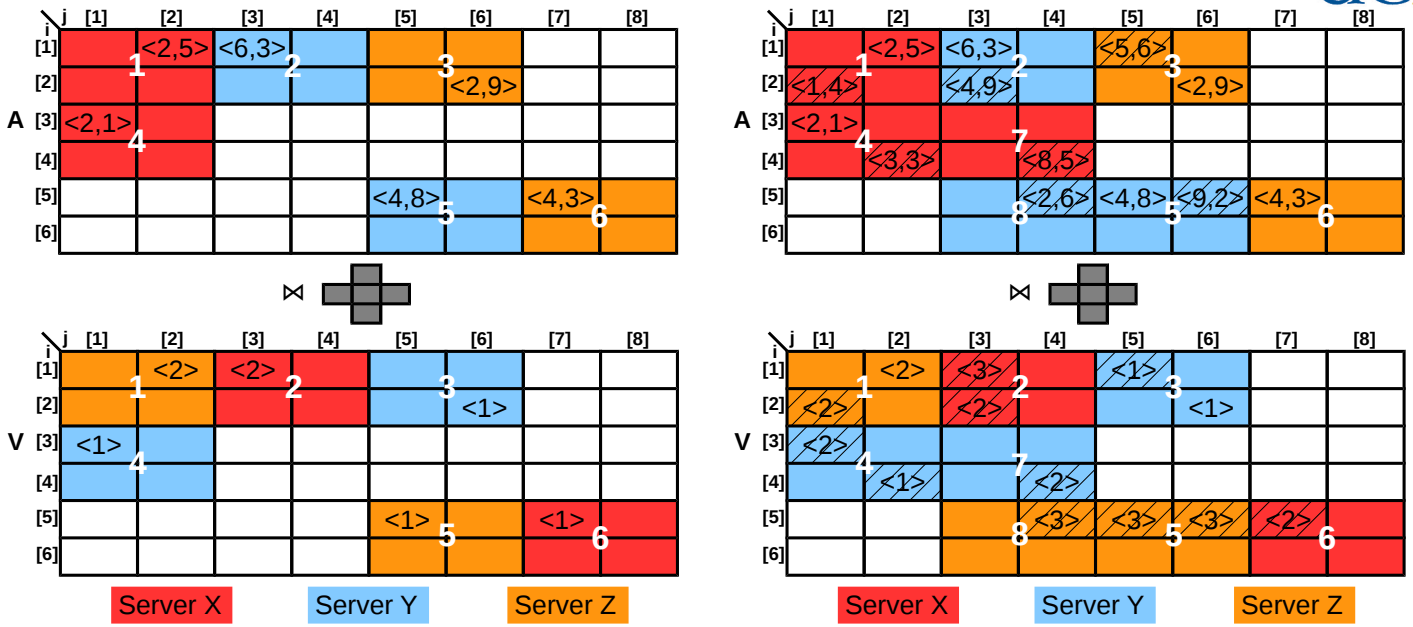
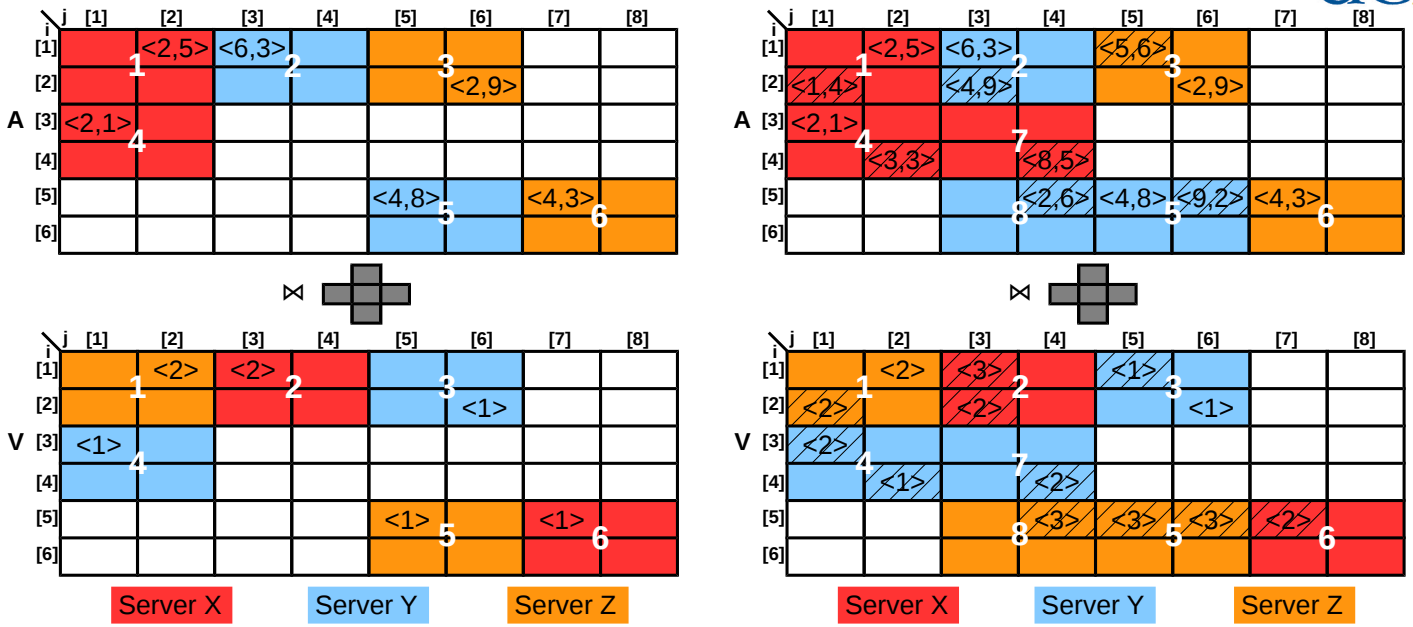
Baseline Array View Maintenance



- For each update batch ΔD:
  - Assign ΔD to node according to chunking strategy
  - $Q(D, \Delta D)$ – differential view computation
  - $M(D) + \Delta Q(D, \Delta D)$ – view aggregation

Baseline Array View Maintenance



- For each update batch ΔD:
  - Assign ΔD to node according to chunking strategy
  - $Q(D, \Delta D)$ – differential view computation
  - $M(D) + \Delta Q(D, \Delta D)$ – view aggregation
- Excessive communication
- Load imbalance

Optimal Array View Maintenance

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- Array chunk (view chunk) reassignment – not stuck with an unfavorable static chunking strategy

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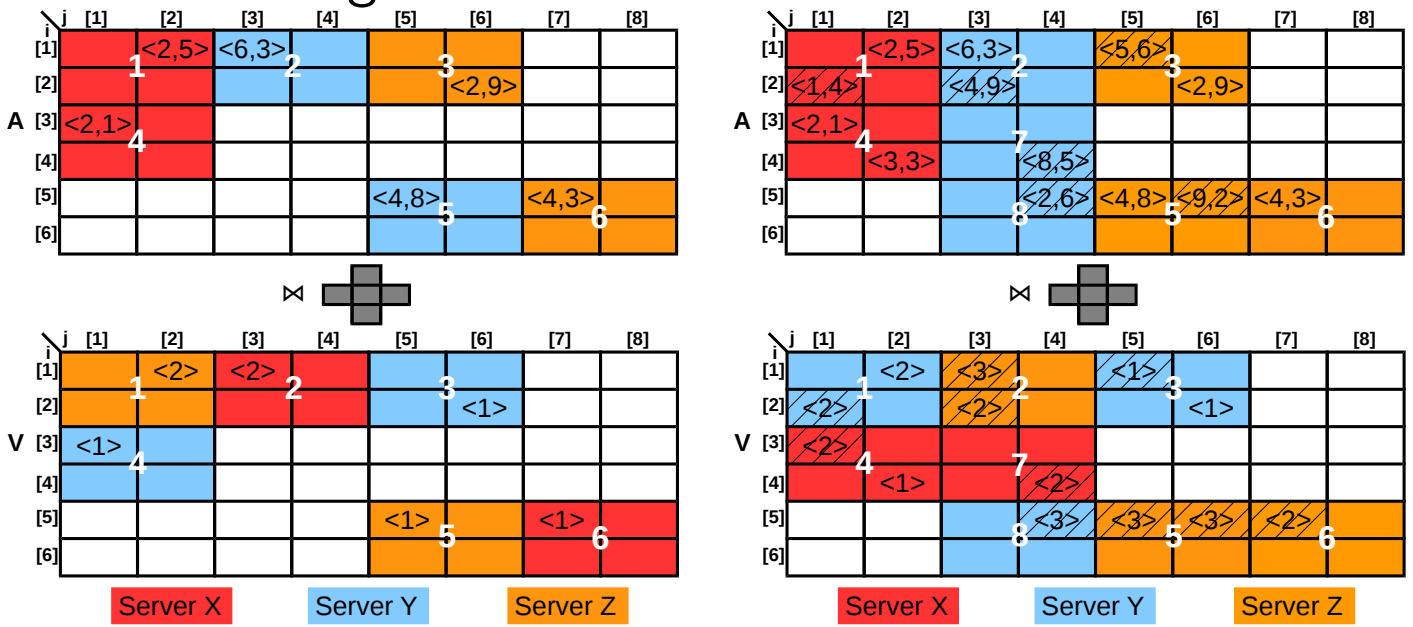

Analytical Cost Model

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$$\min\left\{\lambda\cdot\max\left\{\max_k\left\{\sum_{i,j}^{k\neq j}x_{ikj}\cdot B_i T_{ntwk}+\sum_{p,q,v,j}^{k\neq j,(p,q,v)\in U_0}z_{pqk}\cdot y_{vj}\cdot B_{pq}T_{ntwk}\right\},\right.\right.$$
$$\left.\left.\max_k\left\{\sum_{p,q}z_{pqk}\cdot B_{pq}T_{cpu}\right\}\right\}$$
$$+(1-\lambda)\cdot\max\left\{\max_k\left\{\sum_{i,j}^{k\neq j}x'_{ikj}\cdot B_i T_{ntwk}+\sum_{p,q,v,j,l}^{k\neq j,(p,q,v)\in U_l}z'_{pqk}\cdot y_{vj}\cdot W_l B_{pq}T_{ntwk}\right\},\right.$$
$$\left.\left.\max_k\left\{\sum_{p,q,l}^{(p,q)\in U_l}z'_{pqk}\cdot W_l B_{pq}T_{cpu}\right\}\right\}\right\}$$

Network time to transfer chunks

Network time to transfer partial join results

CPU time to compute aggregations

Three-stage Heuristic

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Complicated formulation $\rightarrow$ decoupling

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Complicated formulation $\rightarrow$ decoupling

- Differential view computation $\rightarrow$ x_{ikj}, z_{pqk}
- View chunk reassignment $\rightarrow$ y_{vj}
- Array chunk reassignment $\rightarrow$ y_{aj}

Differential View Computation

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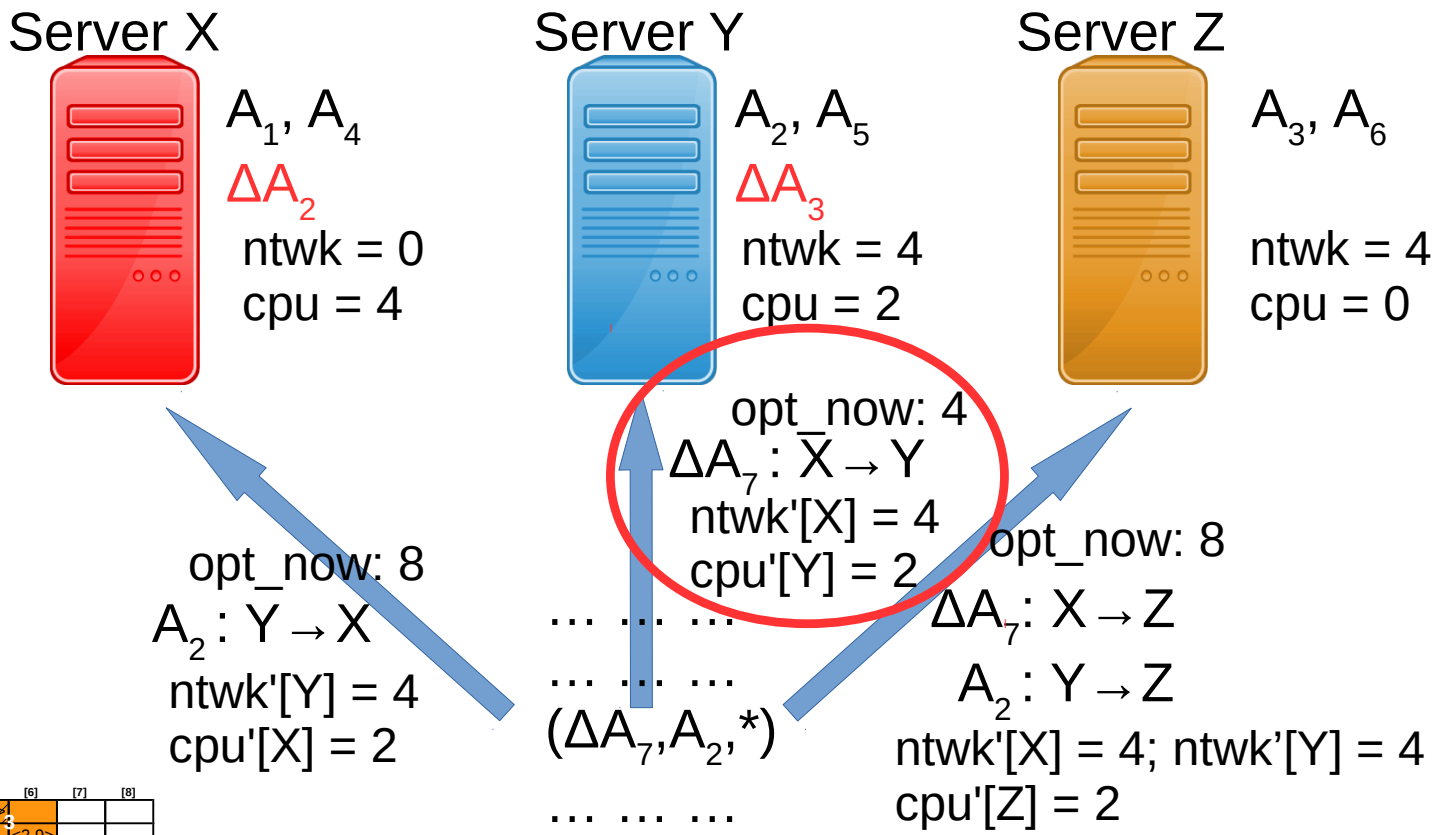
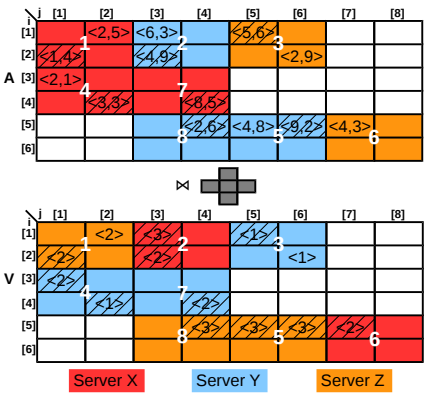


opt_now = max{ntwk + ntwk', cpu + cpu'}



View Chunk Reassignment

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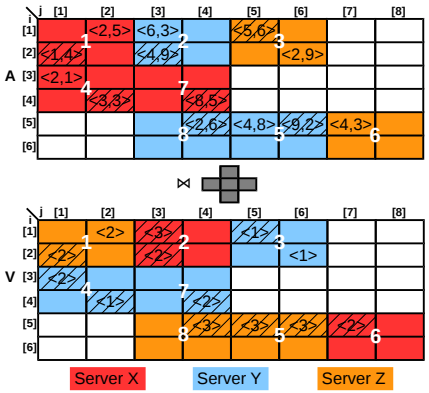
server	*ntwk*	*cpu*
X	32	36
Y	36	30
Z	30	35

join result	server
$J_1 : \Delta A_1 \bowtie A_1$	X
$J_2 : \Delta A_4 \bowtie A_1$	X
$J_3 : \Delta A_2 \bowtie A_1$	Y

$V_1 \rightarrow$	transfers	*ntwk′*	*cpu′*	*opt_now*
X	J_3	$Y = 4$	$X = 6$	42
Y	J_1, J_2	$X = 8$	$Y = 6$	**40**
Z	J_1, J_2, J_3	$X = 8,\ Y = 4$	$Z = 6$	41



Array Chunk Reassignment

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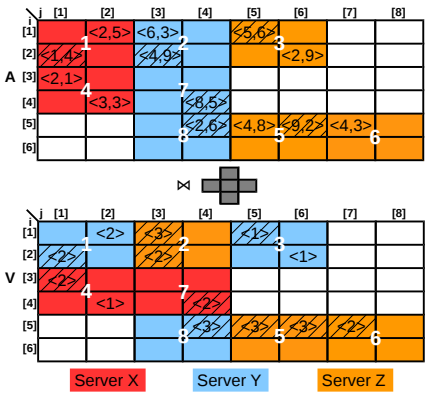
score	
A_2, V_1	8
A_1, V_1	6
A_1, V_2	4
A_2, V_3	4
A_3, V_3	2
...	

server	views	cpu_thr
X	V_2, V_6	4
Y	V_1, V_4, V_7	3
Z	V_3, V_5, V_8	1

	A_1	A_2	A_3	...
size	1	1	1	...
replica	X, Z	Y, Z	Z, Y	



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View Maintenance Time

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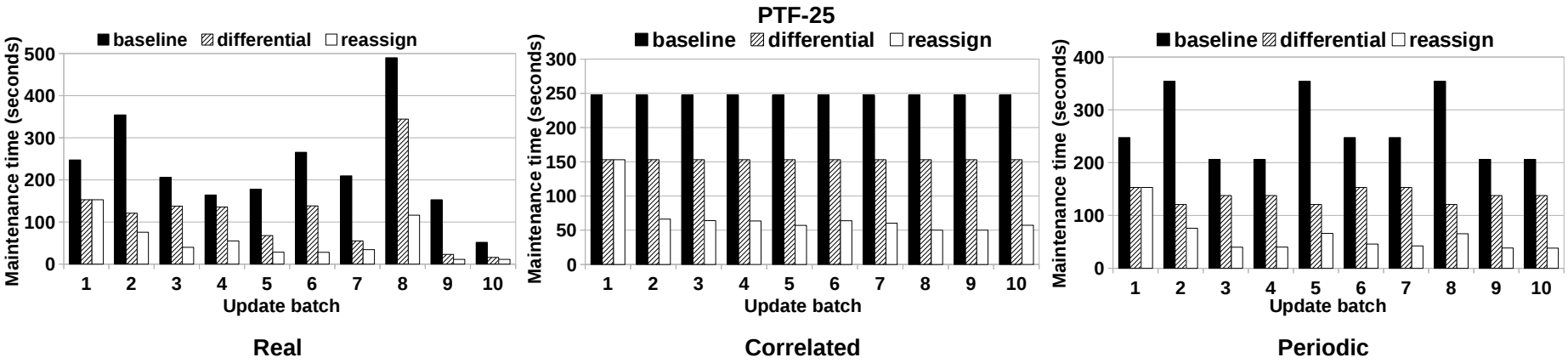
`PTF[time=1,153064;ra=1,100000;dec=1,50000]`

1 billion time-stamped objects, 343 GB



- Real: real updates from PTF pipeline
- Correlated: updates focusing on the same place
- Periodic: updates from several regions periodically – 1, 2, 3, 3, 2, 1, ...

Average Optimization Time per Update Batch

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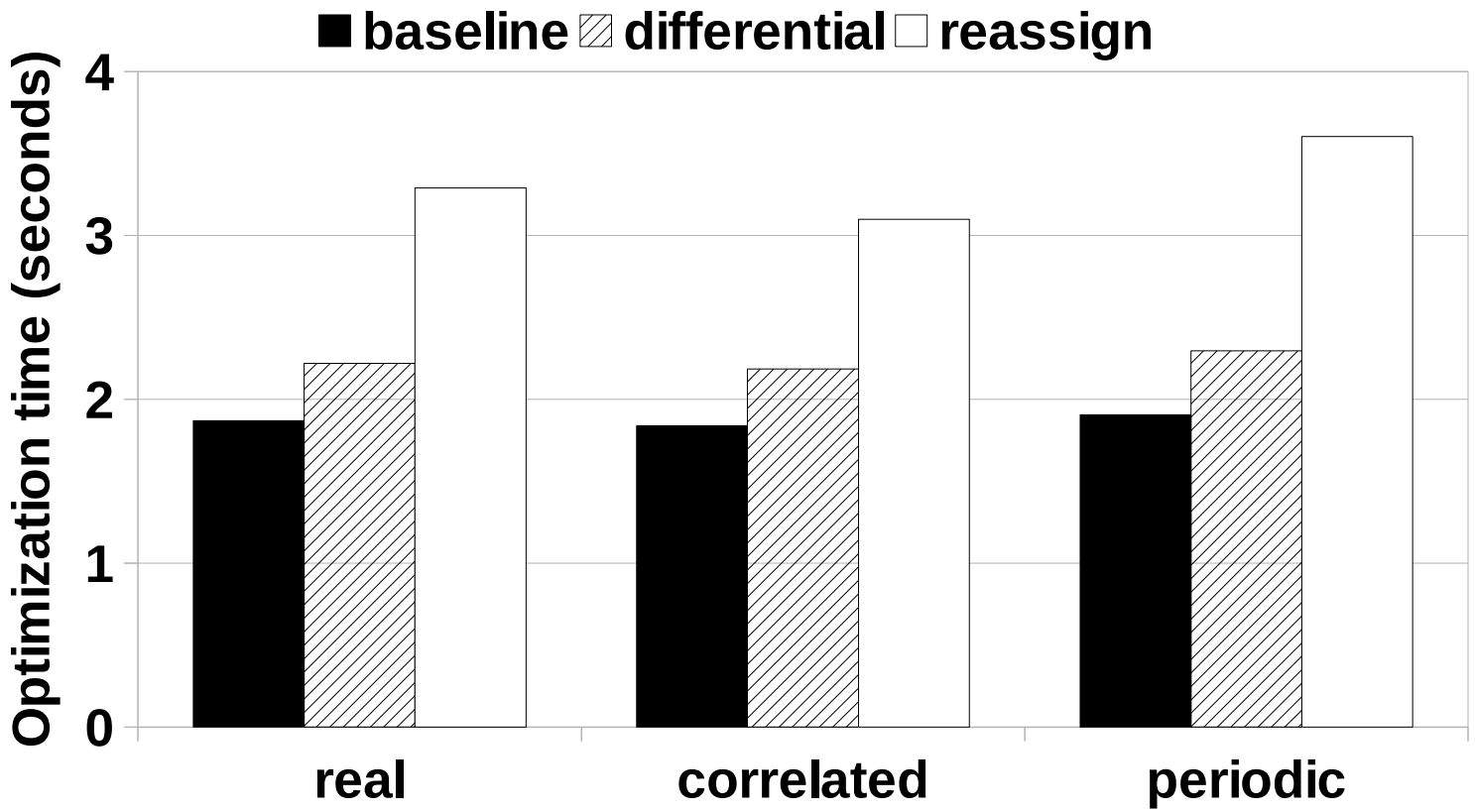

Sensitivity to #Batches

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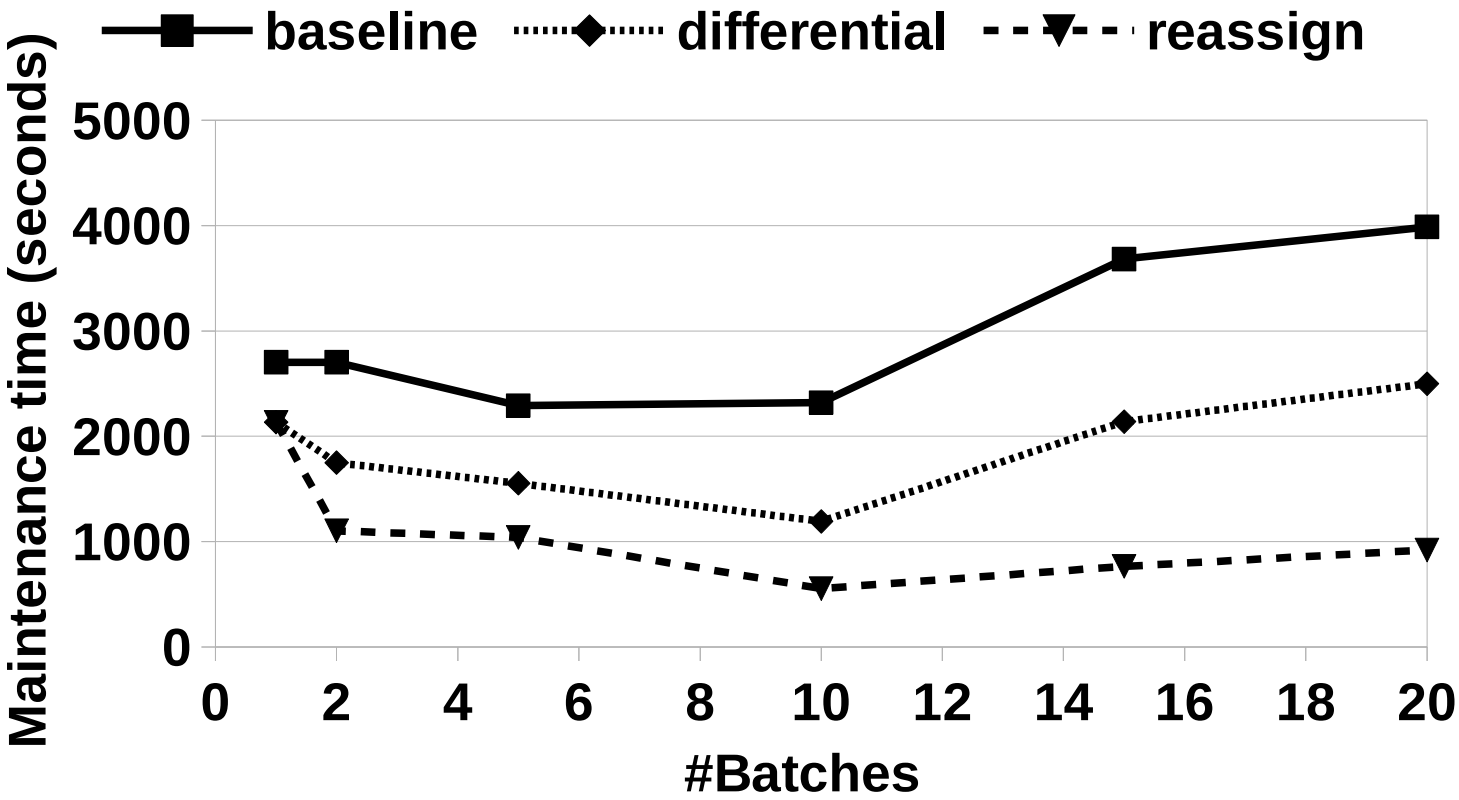

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- Experimental results confirm the effectiveness of the heuristics and the quality of the maintenance plan
- Incrementally maintain the production PTF "association table" and help find rare supernovae at Berkeley Lab and CalTech

Thank you!
Questions?