

## Considerations for TAO

- Must handle large datasets.
- Average request in hours (ideally minutes).
- Scale over large number of distributed cores.
- Use an SQL capable DB.

How to choose a  
DBMS?

Dataset sizes

Data access patterns

Data representation



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Data access patterns

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## Millennium

- $\approx 750,000,000$  galaxies
- $\approx 300\text{GB}$
- <http://www.mpa-garching.mpg.de/galform/virgo/millennium>

## Bolshoi

- $\approx 2,500,000,000$  galaxies
- $\approx 1\text{TB}$
- <http://hipacc.ucsc.edu/Bolshoi>



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## Science Modules

Lightcone

Mock Image

SED

Telescope

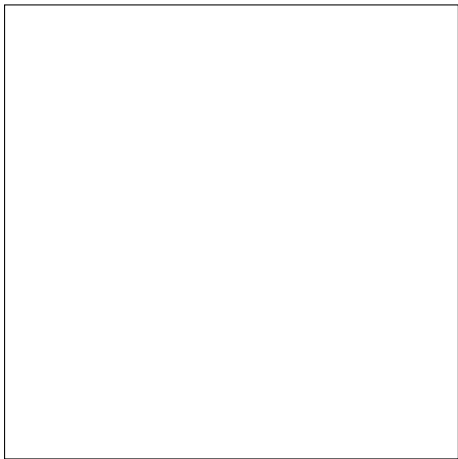
## Science Modules

Lightcone

Mock Image

SED

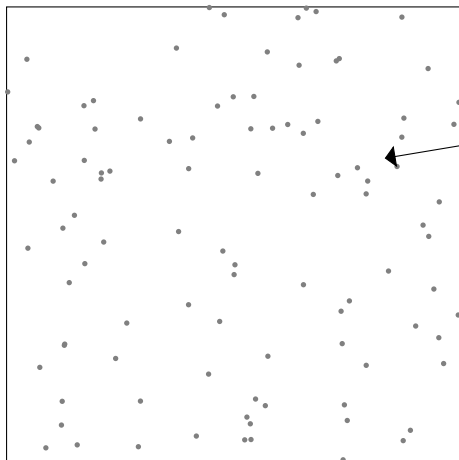
Telescope



simulation domain

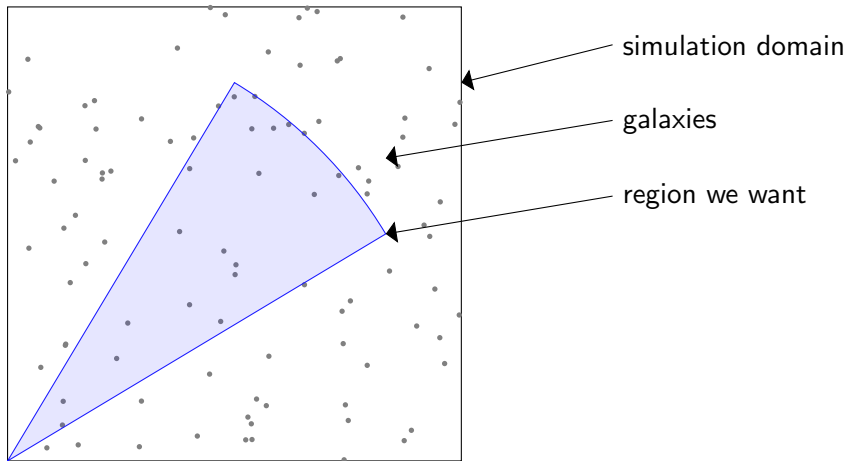


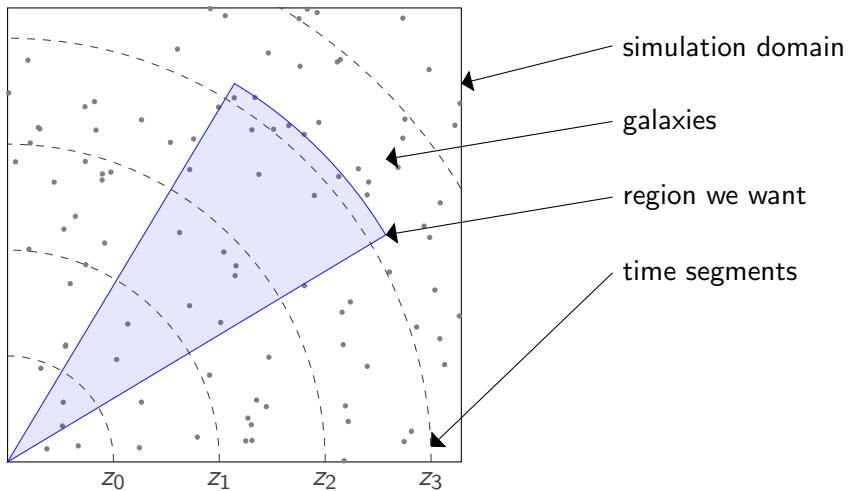




simulation domain

galaxies





```
SELECT * FROM snapshot_004 WHERE (9437.5 + IF(39.8397 + Pos1 < 62.5,  
39.8397 + Pos1, Pos1 + 39.8397-62.5) - 0) < 9427.7048129608065 AND (9437.5 +  
IF(39.8397 + Pos1 < 62.5, 39.8397 + Pos1, Pos1 + 39.8397-62.5) - 0) >  
9408.2000081888491 AND (187.5 + IF(26.503 + Pos2 < 62.5, 26.503 + Pos2, Pos2 +  
26.503-62.5) - 3.45846e-323) < 246.78854155076195 AND (187.5 + IF(26.503 + Pos2  
< 62.5, 26.503 + Pos2, Pos2 + 26.503-62.5) - 3.45846e-323) > 0 AND (187.5 +  
IF(55.9087 + Pos3 < 62.5, 55.9087 + Pos3, Pos3 + 55.9087-62.5) - 6.90856e-310) <  
246.78854155076195 AND (187.5 + IF(55.9087 + Pos3 < 62.5, 55.9087 + Pos3, Pos3  
+ 55.9087-62.5) - 6.90856e-310) > 0 AND SQRT(POW((9437.5 + IF(39.8397 + Pos1  
< 62.5, 39.8397 + Pos1, Pos1 + 39.8397-62.5) - 0), 2)
```

+ POW(((187.5 + IF(26.503 + Pos2 < 62.5, 26.503 + Pos2, Pos2 + 26.503-62.5) -  
 3.45846e-323), 2) + POW(((187.5 + IF(55.9087 + Pos3 < 62.5, 55.9087 + Pos3, Pos3  
 + 55.9087-62.5) - 6.90856e-310), 2)) < 9427.7048129608065 AND  
 SQRT(POW(((9437.5 + IF(39.8397 + Pos1 < 62.5, 39.8397 + Pos1, Pos1 +  
 39.8397-62.5) - 0), 2) + POW(((187.5 + IF(26.503 + Pos2 < 62.5, 26.503 + Pos2,  
 Pos2 + 26.503-62.5) - 3.45846e-323), 2) + POW(((187.5 + IF(55.9087 + Pos3 < 62.5,  
 55.9087 + Pos3, Pos3 + 55.9087-62.5) - 6.90856e-310), 2)) > 9414.6512343460909  
 AND SQRT(POW(((9437.5 + IF(39.8397 + Pos1 < 62.5, 39.8397 + Pos1, Pos1 +  
 39.8397-62.5) - 0), 2) + POW(((187.5 + IF(26.503 + Pos2 < 62.5, 26.503 + Pos2,  
 Pos2 + 26.503-62.5) - 3.45846e-323), 2) + POW(((187.5 + IF(55.9087 + Pos3 < 62.5,  
 55.9087 + Pos3, Pos3 + 55.9087-62.5) - 6.90856e-310), 2)) < 9427.7048129608065  
 AND

(9437.5 + IF(39.8397 + Pos1 < 62.5, 39.8397 + Pos1, Pos1 + 39.8397 - 62.5) -  
 0)/(SQRT(POW((9437.5 + IF(39.8397 + Pos1 < 62.5, 39.8397 + Pos1, Pos1 +  
 39.8397 - 62.5) - 0), 2) + POW((187.5 + IF(26.503 + Pos2 < 62.5, 26.503 + Pos2,  
 Pos2 + 26.503 - 62.5) - 3.45846e-323), 2))) > 0.070737201667702906 AND (9437.5 +  
 IF(39.8397 + Pos1 < 62.5, 39.8397 + Pos1, Pos1 + 39.8397 - 62.5) -  
 0)/(SQRT(POW((9437.5 + IF(39.8397 + Pos1 < 62.5, 39.8397 + Pos1, Pos1 +  
 39.8397 - 62.5) - 0), 2) + POW((187.5 + IF(26.503 + Pos2 < 62.5, 26.503 + Pos2,  
 Pos2 + 26.503-62.5) - 3.45846e-323), 2))) < 1 AND SQRT(POW((9437.5 +  
 IF(39.8397 + Pos1 < 62.5, 39.8397 + Pos1, Pos1 + 39.8397-62.5) - 0), 2) +  
 POW((187.5 + IF(26.503 + Pos2 < 62.5, 26.503 + Pos2, Pos2 + 26.503-62.5) -

$$\begin{aligned}
 & 3.45846e-323), 2)) / (\text{SQRT}(\text{POW}((9437.5 + \text{IF}(39.8397 + \text{Pos1} < 62.5, 39.8397 + \\
 & \text{Pos1}, \text{Pos1} + 39.8397 - 62.5) - 0), 2) + \text{POW}((187.5 + \text{IF}(26.503 + \text{Pos2} < 62.5, \\
 & 26.503 + \text{Pos2}, \text{Pos2} + 26.503 - 62.5) - 3.45846e-323), 2) + \text{POW}((187.5 + \\
 & \text{IF}(55.9087 + \text{Pos3} < 62.5, 55.9087 + \text{Pos3}, \text{Pos3} + 55.9087 - 62.5) - 6.90856e-310), \\
 & 2))) > 0.070737201667702906 \text{ AND } \text{SQRT}(\text{POW}((9437.5 + \text{IF}(39.8397 + \text{Pos1} < \\
 & 62.5, 39.8397 + \text{Pos1}, \text{Pos1} + 39.8397 - 62.5) - 0), 2) + \text{POW}((187.5 + \text{IF}(26.503 + \\
 & \text{Pos2} < 62.5, 26.503 + \text{Pos2}, \text{Pos2} + 26.503 - 62.5) - 3.45846e-323), \\
 & 2)) / (\text{SQRT}(\text{POW}((9437.5 + \text{IF}(39.8397 + \text{Pos1} < 62.5, 39.8397 + \text{Pos1}, \text{Pos1} + \\
 & 39.8397 - 62.5) - 0), 2) + \text{POW}((187.5 + \text{IF}(26.503 + \text{Pos2} < 62.5, 26.503 + \text{Pos2}, \\
 & \text{Pos2} + 26.503 - 62.5) - 3.45846e-323), 2) + \text{POW}((187.5 + \text{IF}(55.9087 + \text{Pos3} < 62.5, \\
 & 55.9087 + \text{Pos3}, \text{Pos3} + 55.9087 - 62.5) - 6.90856e-310), 2))) < 1
 \end{aligned}$$

Very large amount of data to search  
+ Complicated SQL query  
+ Multiple users  
= Trouble

#### Solution

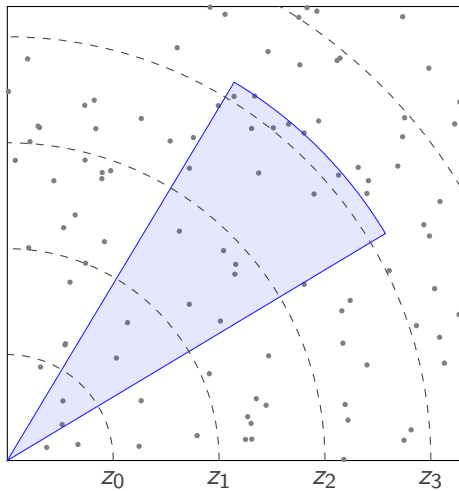
Distribute over multiple servers.



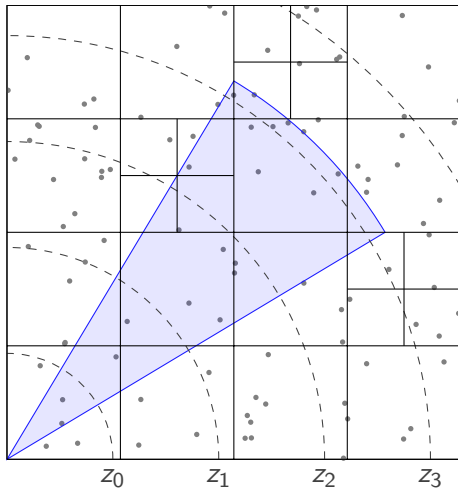
## Distributed DBMS Systems

- MySQL Cluster
  - Difficult to manage.
- pgpool
  - Bugs with some queries.
- PostgresXC
  - Older PostgresQL.
  - Small development team.
- Custom (PostgresQL)
  - Reinventing the wheel?

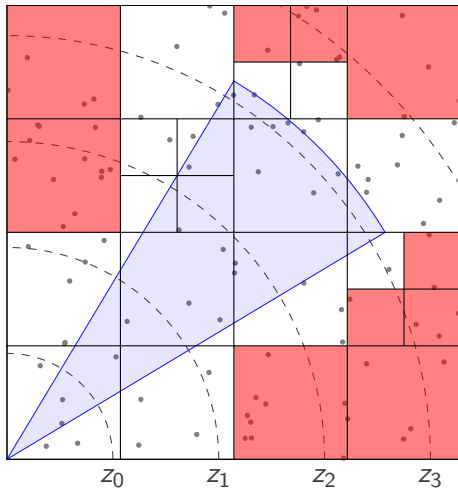
We can do better!



We can do better!



We can do better!



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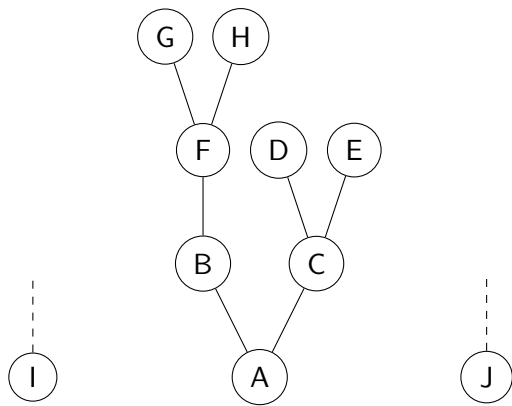
## Science Modules

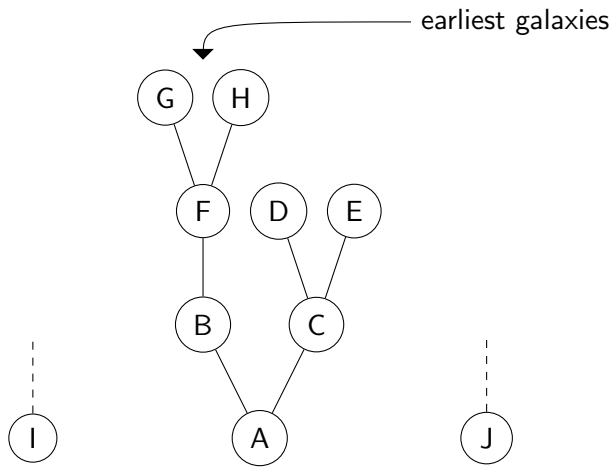
Lightcone

Mock Image

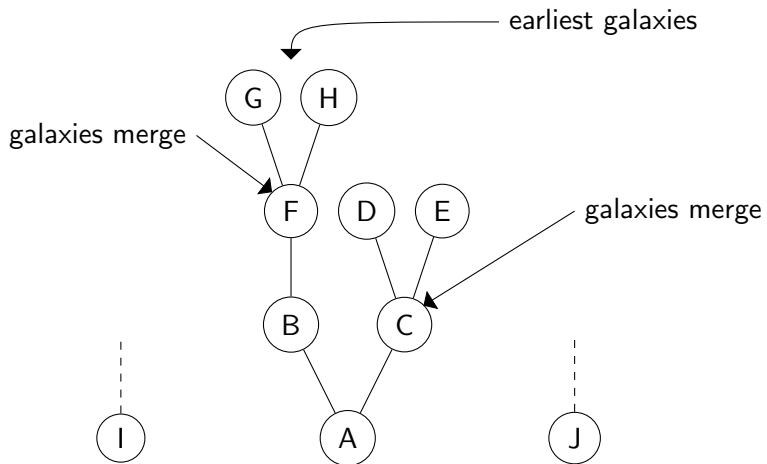
SED

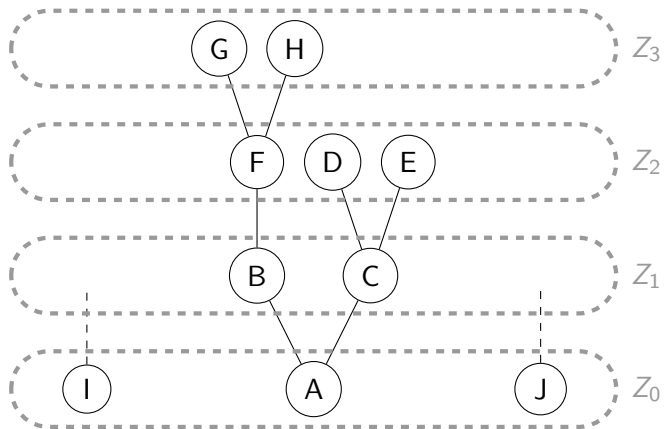
Telescope

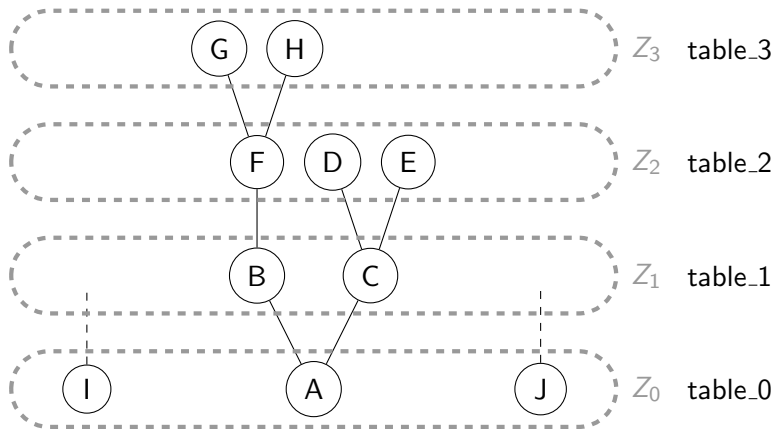


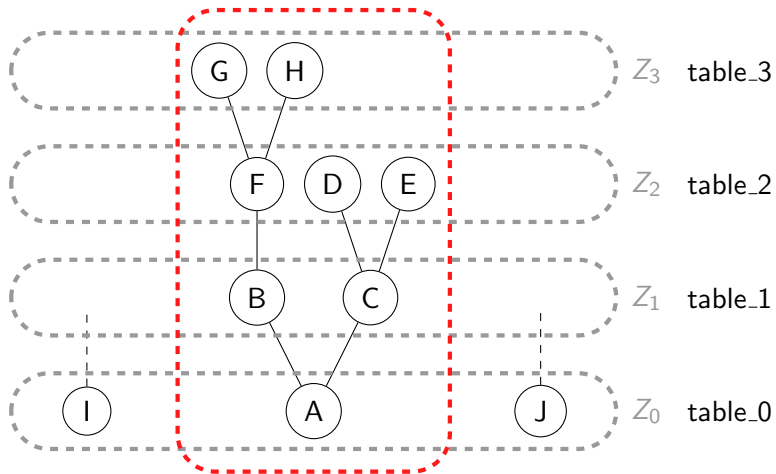




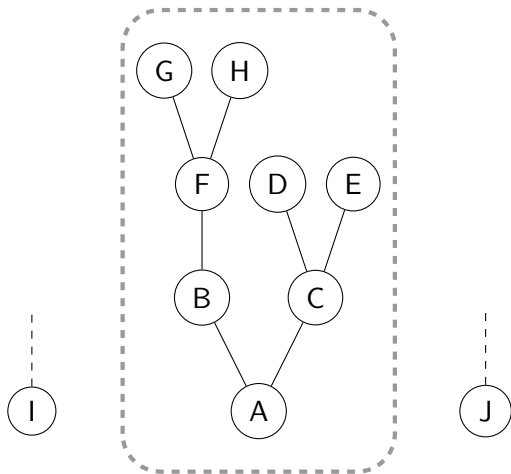








table\_0



Database is looking good...

... what about large computation?

$\approx$  2.5 billion galaxies in Bolshoi dataset, how many to process, on average, per request?

We will need to parallelise computation.

## Science Modules

Lightcone

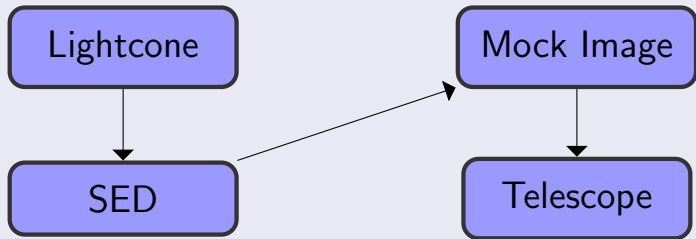
Mock Image

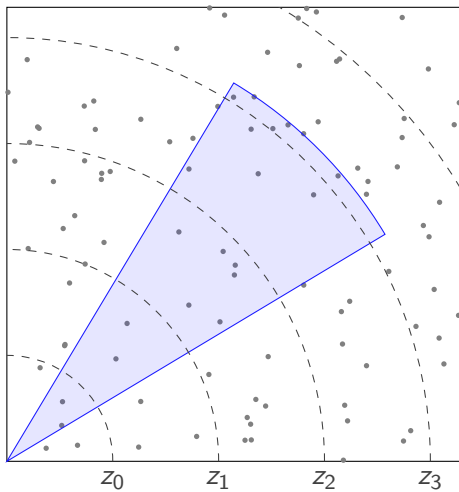
SED

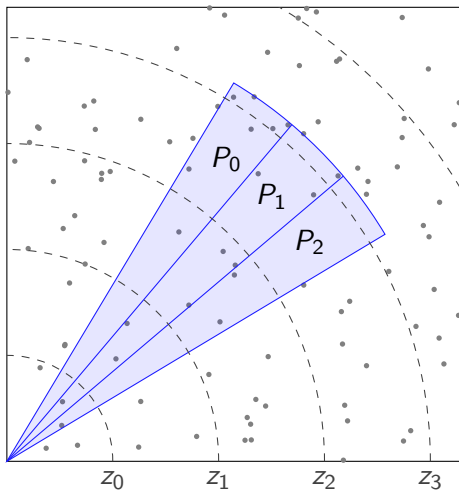
Telescope

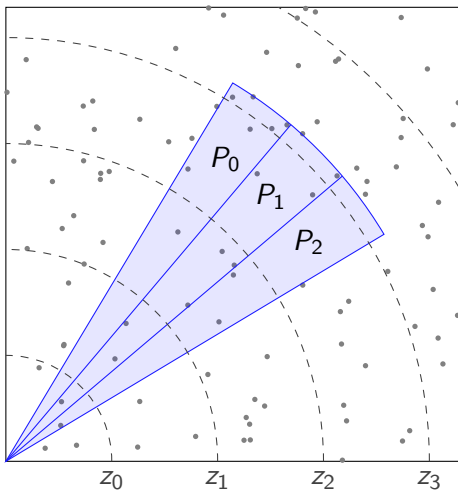


## Science Modules









Balanced? Probably, but  
need to investigate.

We will also utilise GPUs (eventually).

### Algorithms

- Cubic spline interpolation.
- Fourth order Gaussian integration.
- Both easily accelerated by GPUs.