Applications of multiple DBMSs and algorithms for time-domain astronomy

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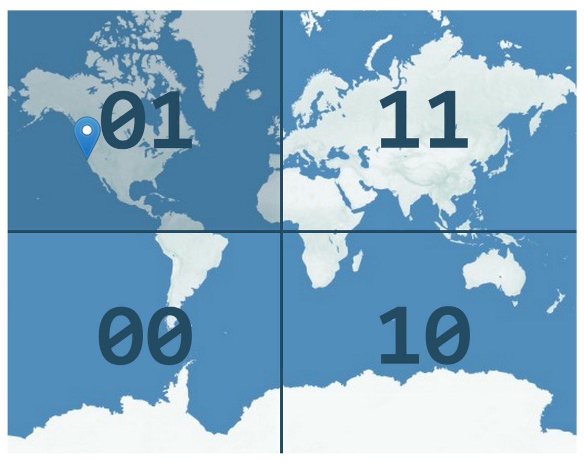
We use multiple DMBSs and algorithms in the follow-up target selection step, processing follow-up observation data, and cataloging reduced data and light curves. The current system is used in our pilot program of time-domain follow-up observations.

1. Redis: GeoSet (a sorted set with latitude and longitude)

Low-latency in-memory spatial data store for astronomical coordinates.

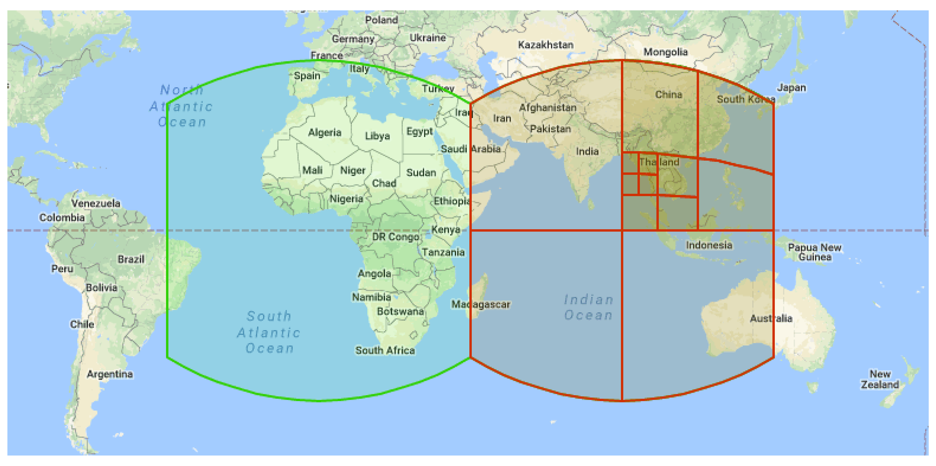
–Modified version of the Redis to store custom catalogs with coordinates for follow–up target selection or local catalog search purposes.
–Typical search response time ~ microseconds to milliseconds thanks to the geohash algorithm.

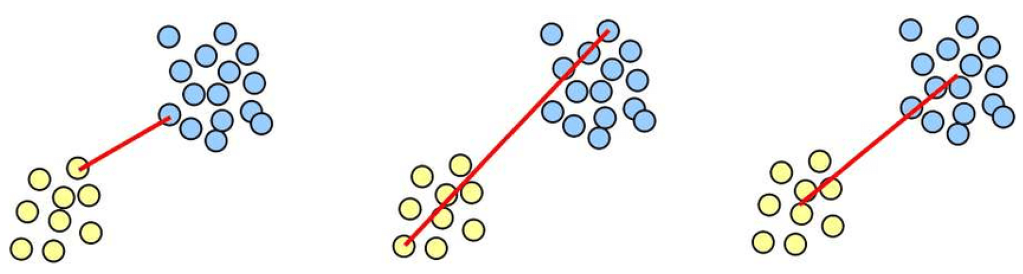
Local custom catalog database



Geohash algorithm

2. Google's S2 Geometry library


Google's S2 Geometry library



Constructing light curves and physical object catalogs by single–linkage (i.e., friends–of–friends) clustering of detected sources with helps of **Google's S2 Geometry library for fast spatial search**.

– Input: catalogs of detected sources with their positions in optical observations for given observation fields.
– Output: light curves and physical objects defined as grouped sources with a given linking angular distance in the single–linkage single–level clustering.
– Our program written in C++ using Google's S2 Geometry library for indexing detected sources and searching the nearest neighbor in the single–linkage clustering.

3. ClickHouse: column-oriented DBMS for source and object catalogs

Our requirements for data store of source, object, and image catalogs:
– Horizontally scalable (i.e. sharding) with commodity hardware.
– SQL–like query support.
– Reasonable data ingestion performance.
– Fast search query performance with group by observation field names or for spatiotemporal constraints.

Our consideration and test of three open–source systems: **ClickHouse, RethinkDB, and Vitess**.
– Vitess: (pros) the most powerful choice with the broad supports of MySQL features and sharding with various custom rules, (cons) requirements of the k8s cluster and large resources.
– RethinkDB: (pros) automatic sharding and fast response in ingestion and search, (cons) weak community development and large resources.
– ClickHouse: (pros) the efficient usage of resources, supports of sharding with SQL–like languages, (cons) the limited support of sharding rules and no geodata features. → We adopt the **ClickHouse as the main store of source, object, and image catalogs for their fixed schema and infrequent usage of entire columns**.

```
source_id CHAR(40) NOT NULL,
seq INT UNSIGNED NOT NULL,
# source sequence number (for a specific amp)
filter CHAR(1),
image_id CHAR(40) NOT NULL,
sci_obj_name CHAR(128),
mjd DOUBLE NOT NULL,
# MJD (day)
x DOUBLE NOT NULL,
# X image (SEXTRACTOR KEYWORDS)
y DOUBLE NOT NULL,
# Y image (SEXTRACTOR KEYWORDS)
ra_deg DOUBLE NOT NULL,
# RA world (SEXTRACTOR KEYWORDS; degree)
dec_deg DOUBLE NOT NULL,
# DEC world (SEXTRACTOR KEYWORDS; degree)
ra_dec_point POINT NOT NULL SRID 4326,
mag_auto DOUBLE,
# calibrated Mag. auto (SEXTRACTOR KEYWORDS; mag_auto)
magerr_auto DOUBLE,
# uncertainty of mag_auto (SEXTRACTOR KEYWORDS; mag_auto uncertainty)
bkg DOUBLE,
# background at centroid position (SEXTRACTOR KEYWORDS; ADU)
fwhm DOUBLE,
# FWHM assuming a gaussian core (SEXTRACTOR KEYWORDS; pixel)
ellipticity DOUBLE,
# ELLIPTICITY (SEXTRACTOR KEYWORDS)
class_star DOUBLE,
# S/G classifier output (SEXTRACTOR KEYWORDS)
sex_flag SMALLINT UNSIGNED,
# SExtractor extraction flags (SEXTRACTOR KEYWORDS)
mag_map DOUBLE,
# photometrically calibrated best mag.
# (derived and corrected by MAP; magnitude)
magerr_map DOUBLE,
# uncertainty of mag_map (magnitude)
ap_map DOUBLE,
# aperture diameter for mag_map (pixel)
refmag_map DOUBLE,
# magnitude with Max. AP via MAP (magnitude)
avg_delta_m DOUBLE,
# average of photometric calibration delta_m
std_delta_m DOUBLE,
# standard deviation of photometric calibration delta_m
skew_delta_m DOUBLE,
# skewness of photometric calibration delta_m
source_reliability DOUBLE,
photometry_reliability_n INT
photometry_reliability_1 DOUBLE,
photometry_reliability_2 DOUBLE,
photometry_reliability DOUBLE
```

Source catalog table

4. MongoDB: document-oriented DBMS for light curves

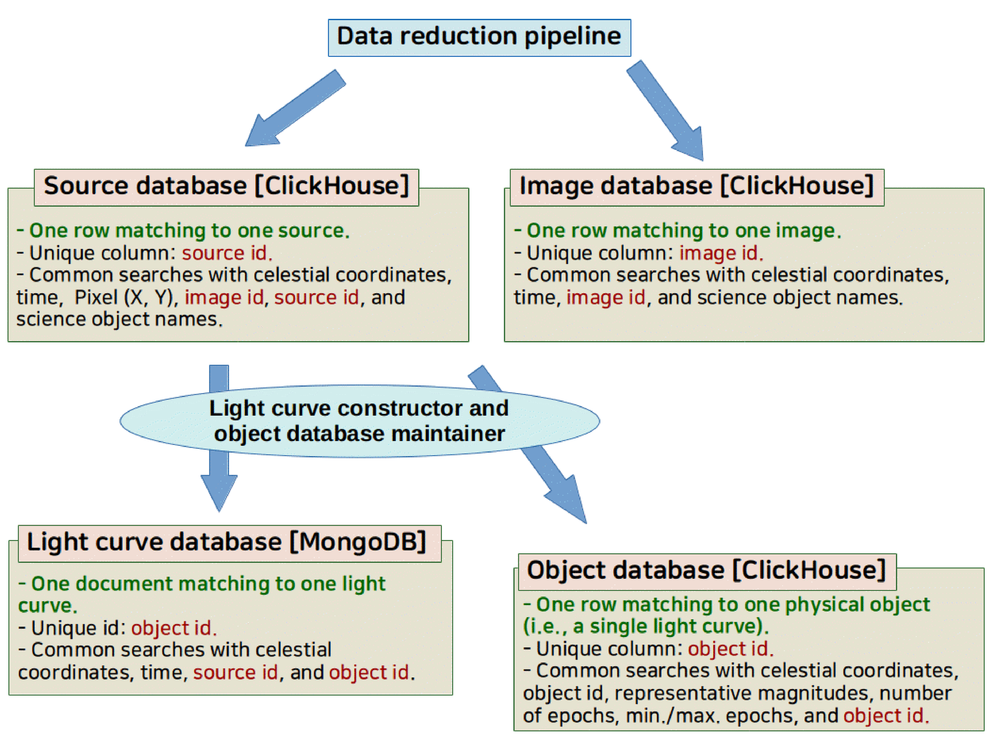
– Why?
a. different sizes and contents of light curves well matched to documents stored in MongoDB.
b. supports of sharding and geodata in document–format data.

```
{
_id: ObjectID(),
(given by mongoDB)
object_id: KMTNJ083025.53-070822.5,
(produced by the constructor as the mean of RA and DEC)
ra: RA,
(mean value for sources with source_reliability >= 19;
degree)
dec: DEC,
(mean value for sources with source_reliability >= 19;
degree)
num_obs_lc: 111,
(number of observation epochs given to the linking
procedure)
num_obs: 107,
(number of observation epochs with reliable sources, i.e.,
source_reliability >= 19, used for the linking procedure)
obs: [
{source_id: 20190123032334p54_CTIO_09_34p73_32p34,
filter: V, mjd: 653109.345572, ra: 34.567456, dec: -
74.341096,
mag_map: 16.564, magerr_map: 0.014,
mag_auto: 16.780, magerr_auto: 0.023,
sex_flag: 0,
source_reliability: 65,
photometry_reliability_n: 23,
photometry_reliability_1: 0.003,
photometry_reliability_2: 0.032,
photometry_reliability: 0.931},
{source_id: 20190123032423p26_CTIO_09_34p71_32p32,
filter: V, mjd: 653109.985572, ra: 34.657456, dec: -
74.341086,
mag_map: 16.545, magerr_map: 0.0143,
mag_auto: 16.791, magerr_auto: 0.021,
sex_flag: 0,
source_reliability: 86,
photometry_reliability_n: 36,
photometry_reliability_1: 0.0013,
photometry_reliability_2: 0.0209,
photometry_reliability: 0.71}
]
process_datetime: date and time in UTC
}
```

Light curve example

5. Plan

–Continuous tests with the current data reduction process and stores for our pilot observation program until Sep. 2020.
– Expanding the current configuration of DBMS nodes in a public cloud from 4 nodes to 8 nodes for ClickHouse and MongoDB, respectively.



Current data reduction process and stores