Challenges and Solutions for Private and Reproducible Environmental Exposure Assessment at Scale

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Geomarkers

Geocoding Converting a string of text into spatial coordinates or boundaries

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place (+ time) → estimating past "exposures"

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- Geomarkers are the most powerful predictor of disease, disorder, injury, and mortality
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- Practical usage for exposure assessment is hindered by
  - large data + inefficient manual data curation
  - the need for technical expertise and software skills
  - privacy restrictions

Protected Health Information

- Confidentiality of research subjects must be safeguarded
- HIPAA-defined "Safe Harbor" provision prohibits sharing of identifiers and quasi-identifiers, such as:
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  - spatial boundary with $<$ 20,000 residents

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  - retrospective consent often not feasible + consent bias
  - IRB and institutional DUA approvals can be lengthy and have different requirements
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- Presents challenges when integrating geomarkers into research studies and clinical applications

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- Independent Geomarker Assessment
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- Existing Software Approaches
  - commercial options are cost prohibitive and aren't designed for batch operations
  - closed source geocoder prevents transparency and reproducibility

Vision

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- FAIR (findable, accessible, interoperable, reusable) data
- *Reproducible* using computable exposures
- *Portable* for sharing and mobility of compute

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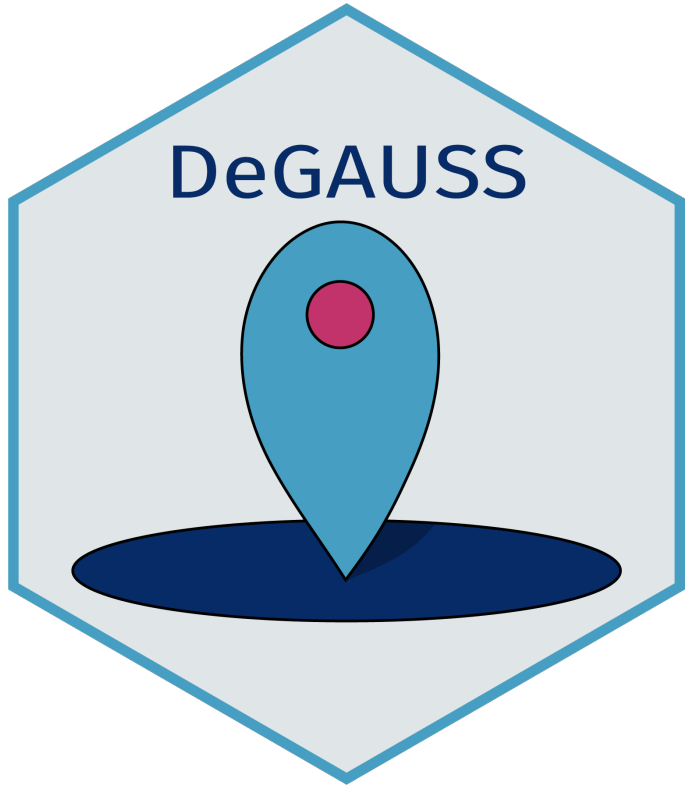
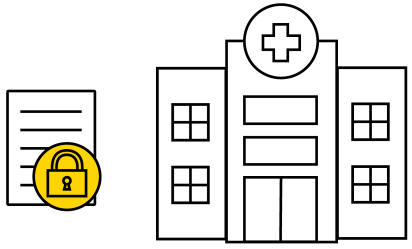
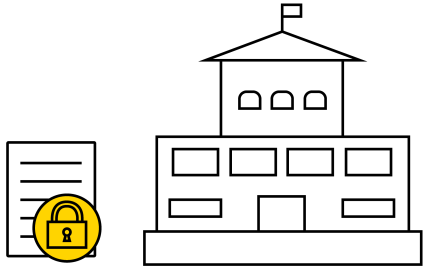
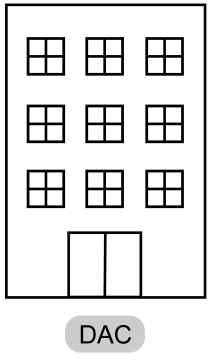


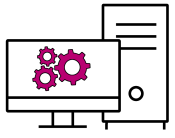
https://degauss.org

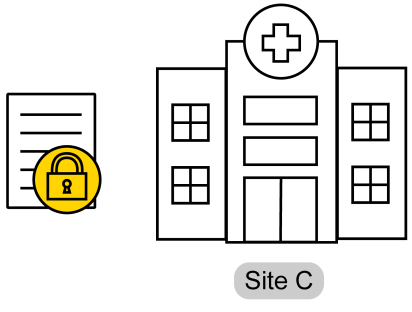
Bringing Computation to Data











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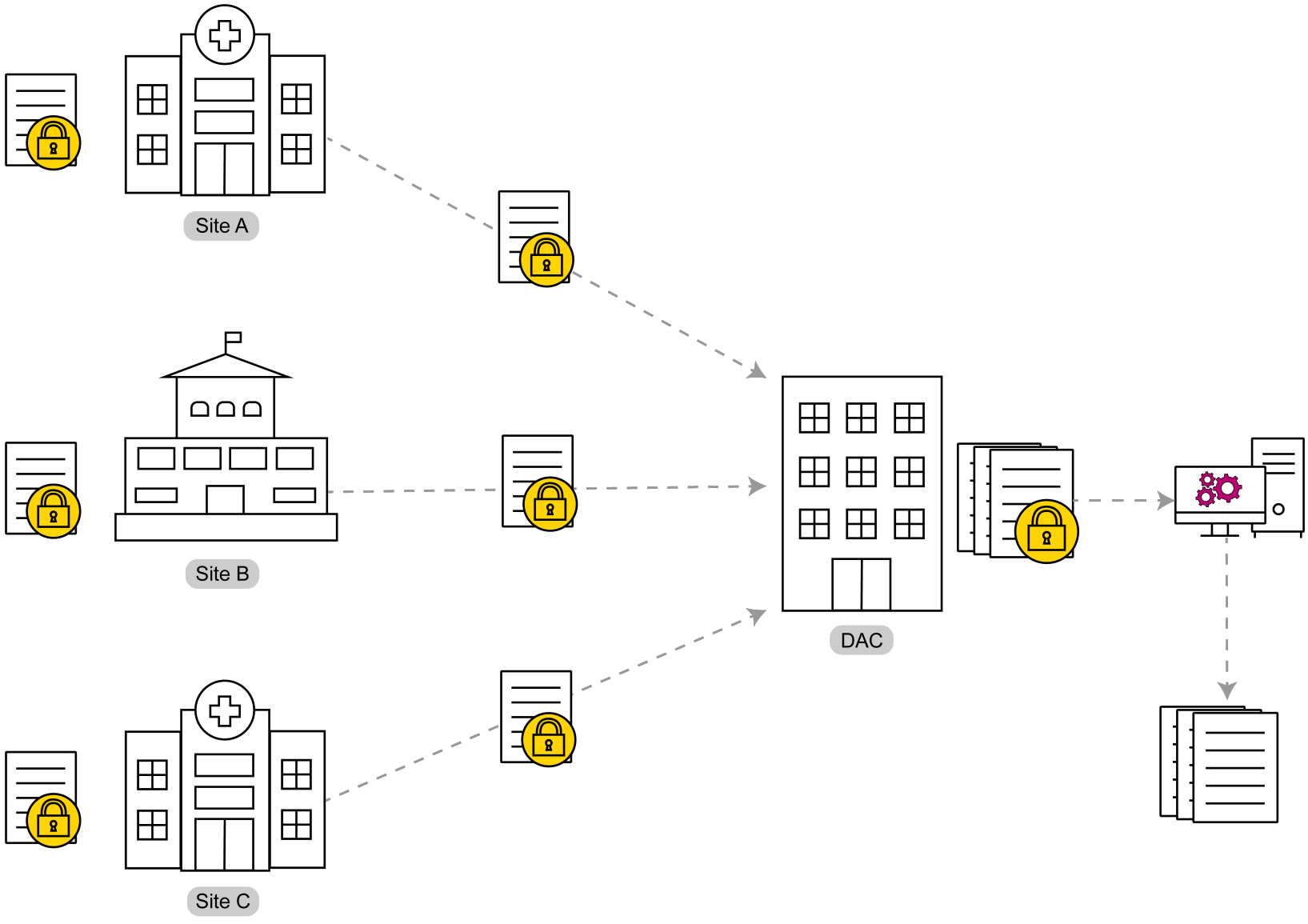

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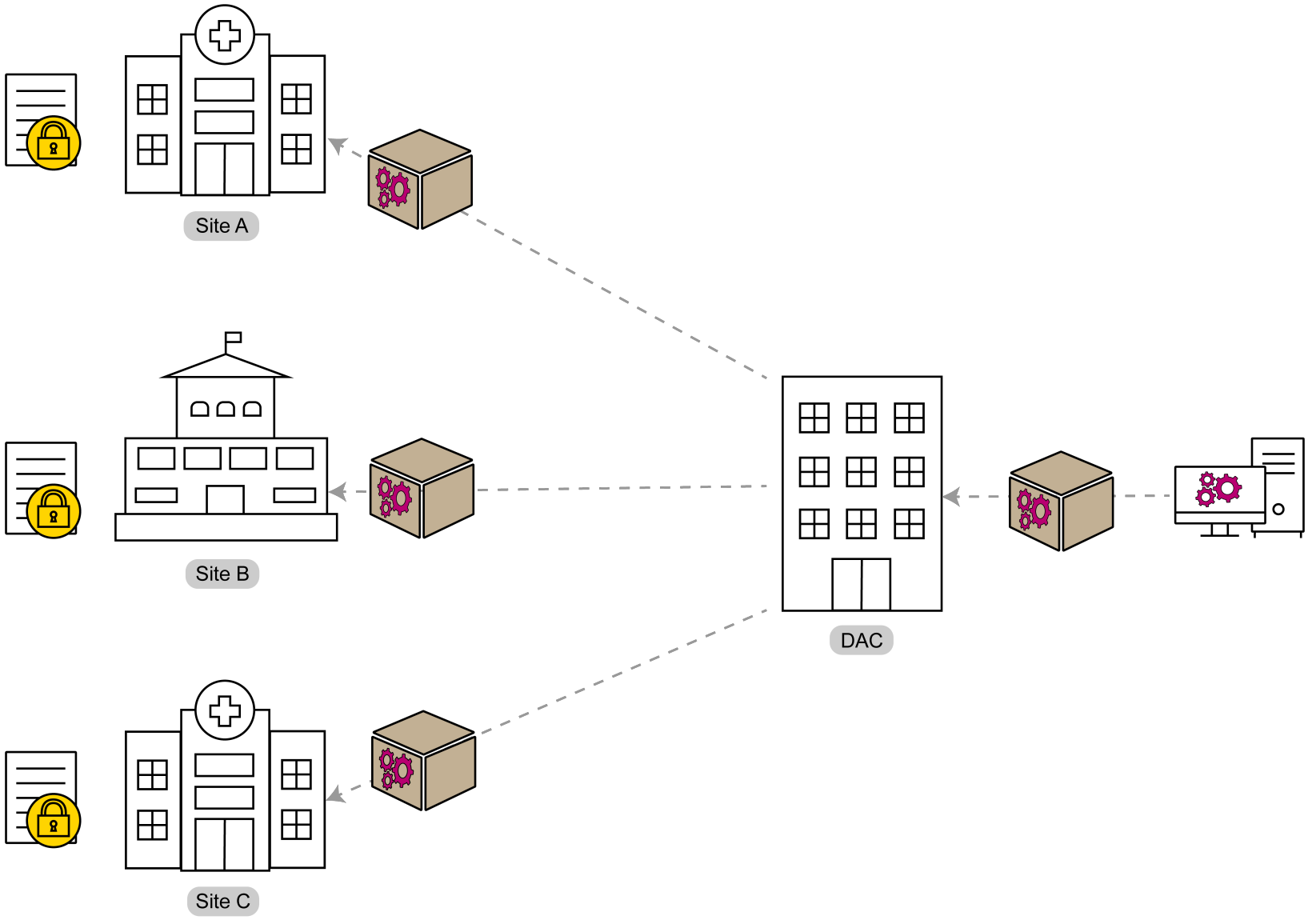

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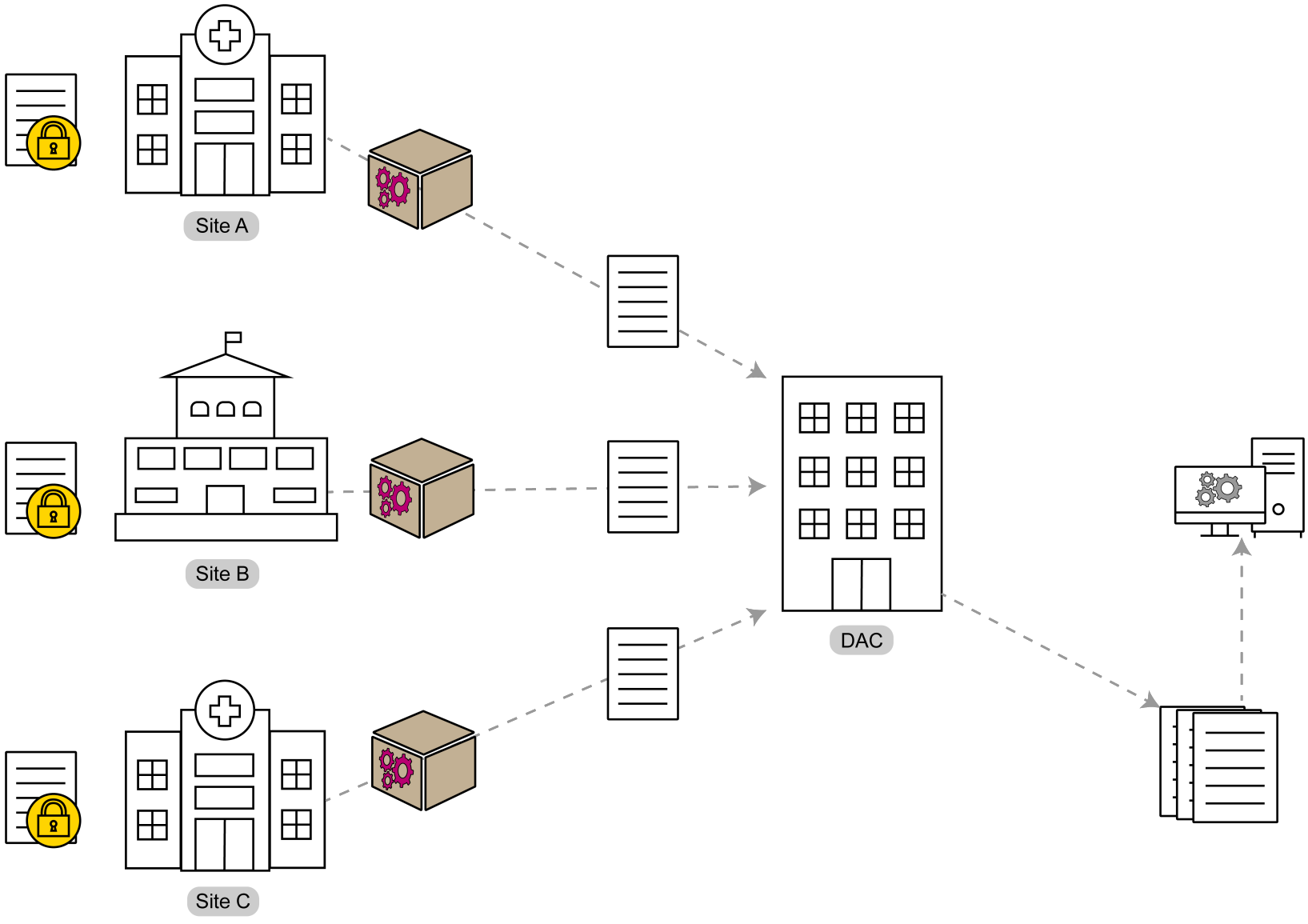

DeGAUSS

- Decentralized but reproducible and standardized
- Container framework that reads and writes CSV files
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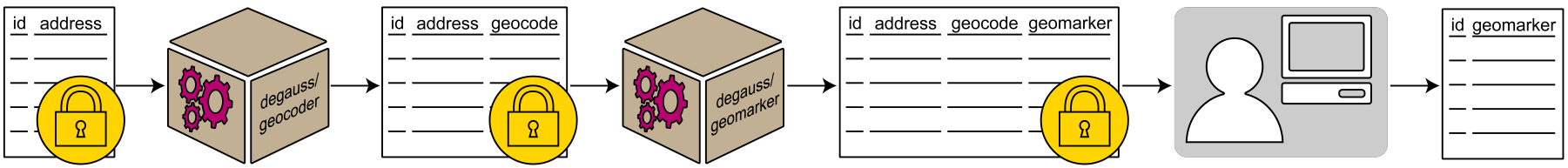

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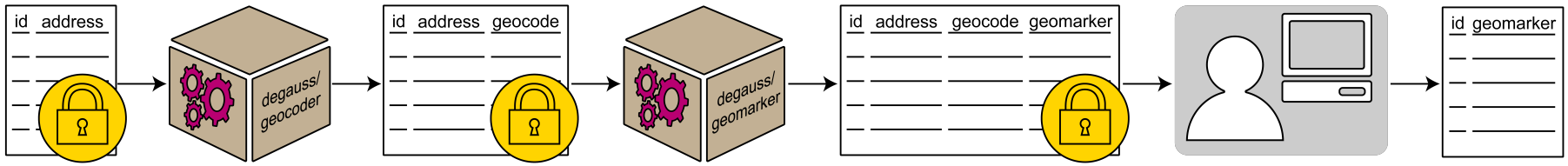

- Free and open source
- Automated and continuous documentation and integration
- Metadata curation and integration
- Multiple user entry-points (data, geomarker assessment code, Docker/OCI images, GUI, stand-alone application)
- Community supports and contributions

Anonymity and Reidentification

- Anonymity can ensure small, but non-zero, chance of reidentification
  - published examples of reidentification attacks by researchers (Sweeney 2017, Boronow 2020)
  - reidentification tasks are rare and often unsuccessful (Emam 2011, Emam 2015)
- Don't conflate re-identification of identifiers with re-identification of quasi-identifiers
  - quasi-identifiers recovered by merging with extant datasets
  - institutional restrictions on sharing of quasi-identifiers

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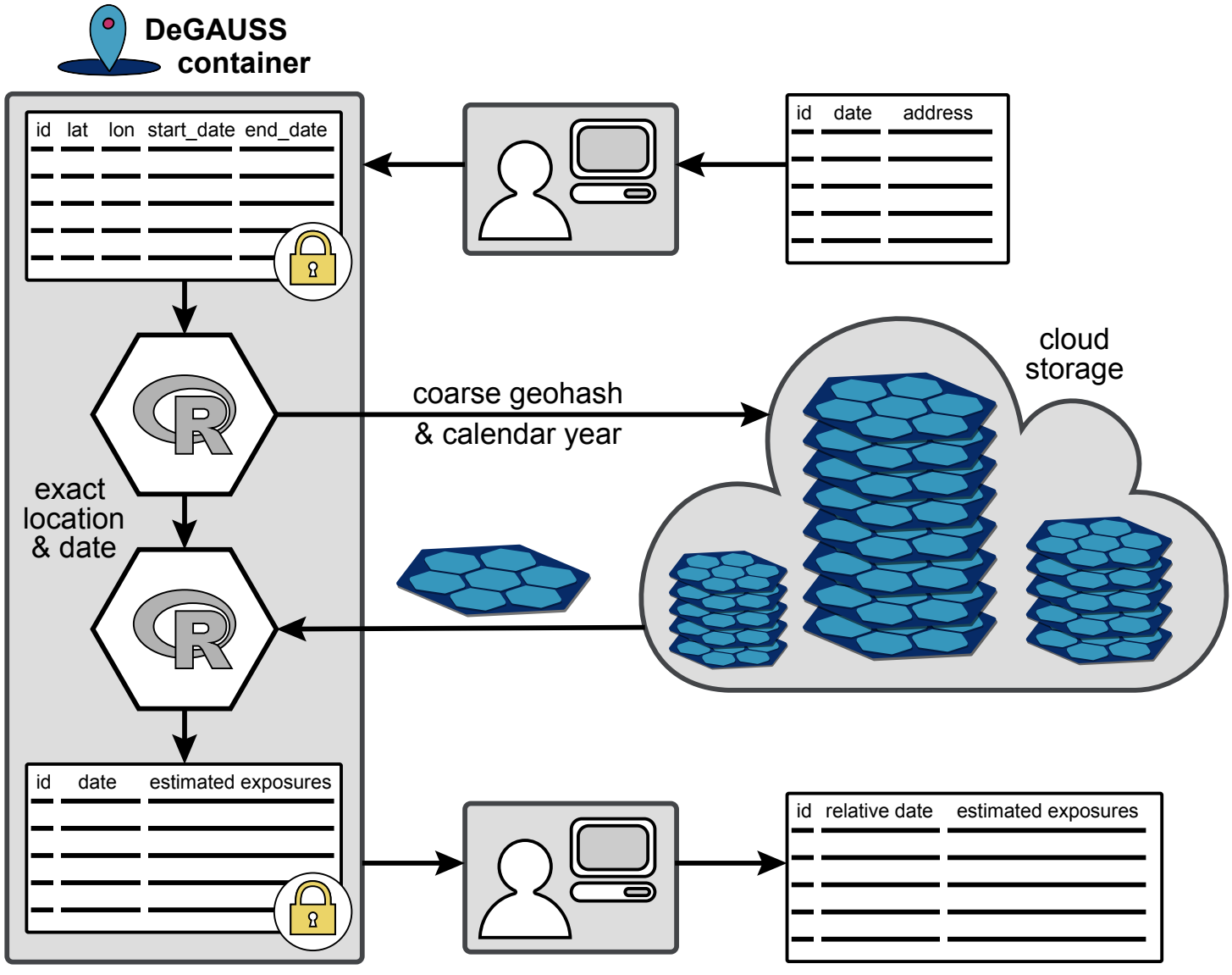
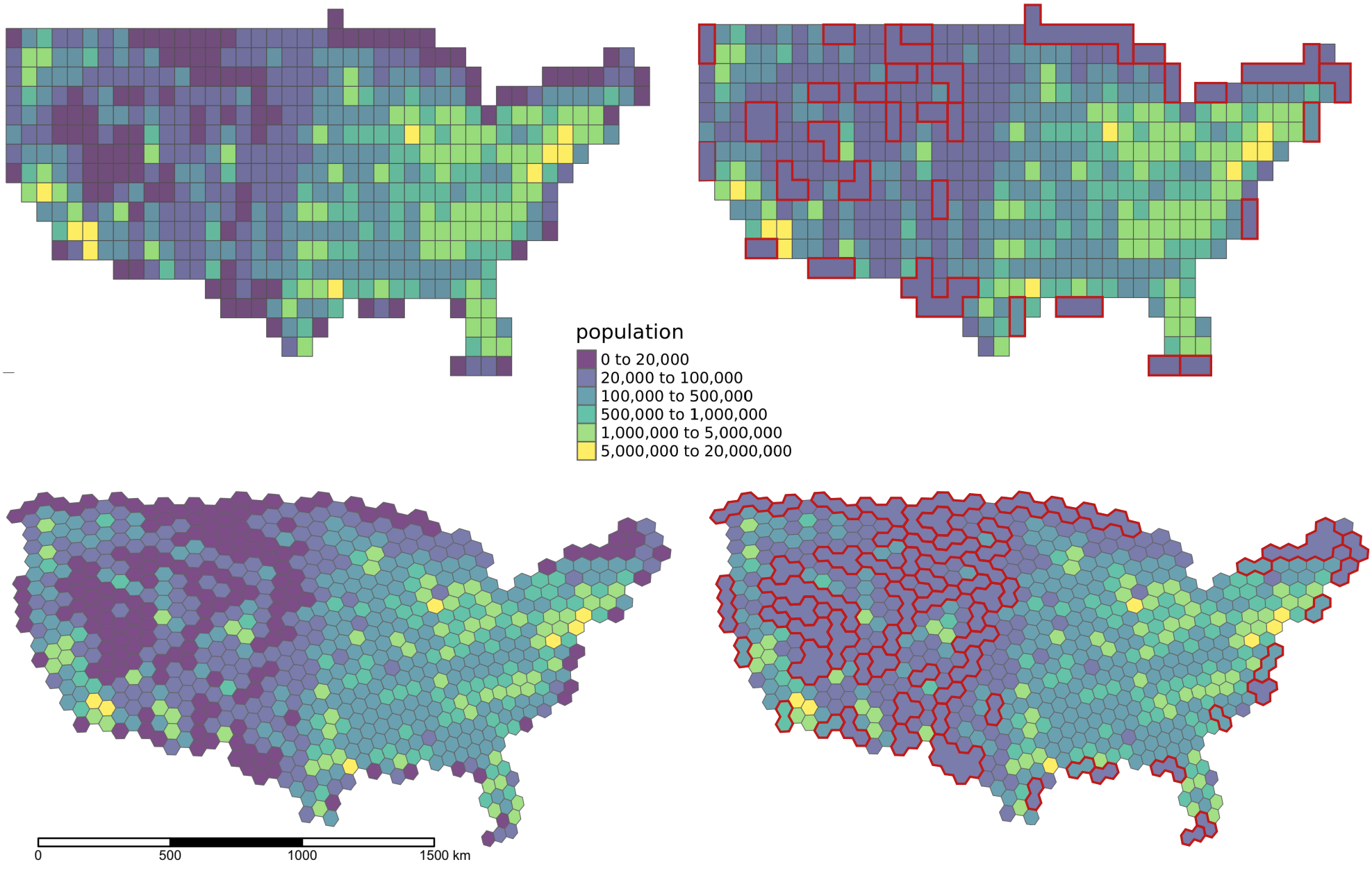
High Resolution Spatiotemporal Geomarkers

- Pre-computed data "products"
  - produced by from interpolation/prediction exposure models
  - often uses publicly available spatiotemporal datasets
  - ambient air pollution, climate, noise, wildfires, crime
- High resolution
  - often < 1 km sq. exposures covering entire country
  - daily estimates covering 2000 - 2021
- Exposure timing
  - used to study acute, short-term, and long-term exposures
  - development-based temporal averages during early life
- Large file sizes require data transmission, when most of data usually not used
- Most approaches currently require sharing PHI with model developer for addition of estimates

Approach


DeGAUSS
container
id lat lon start_date end_date
id date address
cloud
storage
coarse geohash
& calendar year
exact
location
& date
id date estimated exposures
id relative date estimated exposures

Safe Harbor For Downloading Spatial Subsets



Applications

- ECHO, eMERGE, government organizations, electronic health data warehouses
  - different levels of consent, data management and coordination centers
- Applied within DeGAUSS containers for several different daily, high resolution ambient pollution estimates
  - https://degauss.org/pm
  - https://degauss.org/schwartz

Advantages

- Prevents download of unnecessary spatial and/or temporal "slices" of data
- Decreases time and resources needed by end user to run software without sharing PHI
- Automated downloading, parsing, and spatiotemporal joining

DeGAUSS

image*	description	version**
ghcr.io/degauss-org/geocoder	batch geocoding	version v3.0.2
ghcr.io/degauss-org/census_block_group	census block group and tract FIPS	version v0.4.1
ghcr.io/degauss-org/st_census_tract	spatiotemporal census tract FIPS 1970 - 2020	version v0.1.2
ghcr.io/degauss-org/dep_index	census tract-level deprivation index	version v0.1
ghcr.io/degauss-org/roads	proximity and length of major roads	version v0.1
ghcr.io/degauss-org/aadt	average annual daily traffic	version v0.1.1
ghcr.io/degauss-org/greenspace	enhanced vegetation index	version v0.2
ghcr.io/degauss-org/nlcd	land cover (imperviousness, land use, greenness)	version v0.1
ghcr.io/degauss-org/pm	daily PM2.5	version v0.1.3
ghcr.io/degauss-org/narr	daily weather data (air temperature, humidity, etc)	version v0.1
ghcr.io/degauss-org/drivetime	distance and drive time to various care sites	version v1.0
degauss/schwartz_grid_lookup	schwartz grid for spatiotemporal pollutant models	version v0.4.1
degauss/schwartz	daily PM2.5, NO2, and O3 concentrations	version v0.5.5

https://degauss.org/available_images

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Future Directions

- GUI interfaces for researchers and scientists
- Metadata curation for data science workflows and clinical informatics pipelines
- Cloud Optimized Geotiffs (COG)
- Integrating methods for "deidentifying" area-level data
- Homomorphic encryption
- Facilitating community contributions

Discussion

- G x E x **Time**
  - geomarkers and epigenome change over time
  - report back for spatiotemporal exposures
  - less focus on privacy/precision tradeoffs for time
- Geospatial data collection and sharing
  - empower people to donate their own spatiotemporal data collected via cloud-hosted location trackers
  - think about consent in the future: limited sharing of pseudo-identifiers only?

Discussion

- HIPAA Safe Harbor not sufficient to guarantee anonymity, but should this be our goal in research studies?
- Updated guidance & policies needed
  - zip code...
  - details on spatial and temporal generalization strategies
  - update examples to use census-defined boundaries
  - reidentification of pseudo-identifiers versus identifiers
  - how to deal with datasets that may be considered de-identified now, but will change to identified after unforeseen datasets and methods arise?
- Must maintain reproducibility *and* privacy

Thank You

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