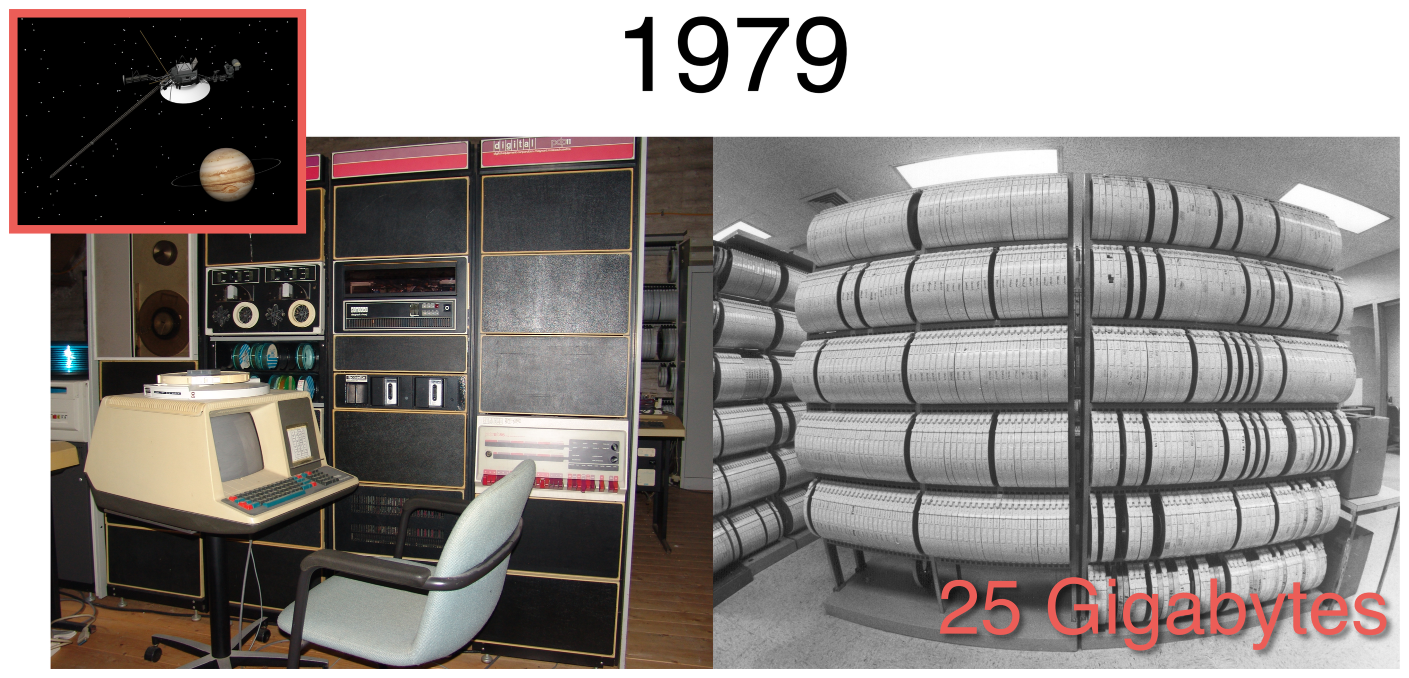
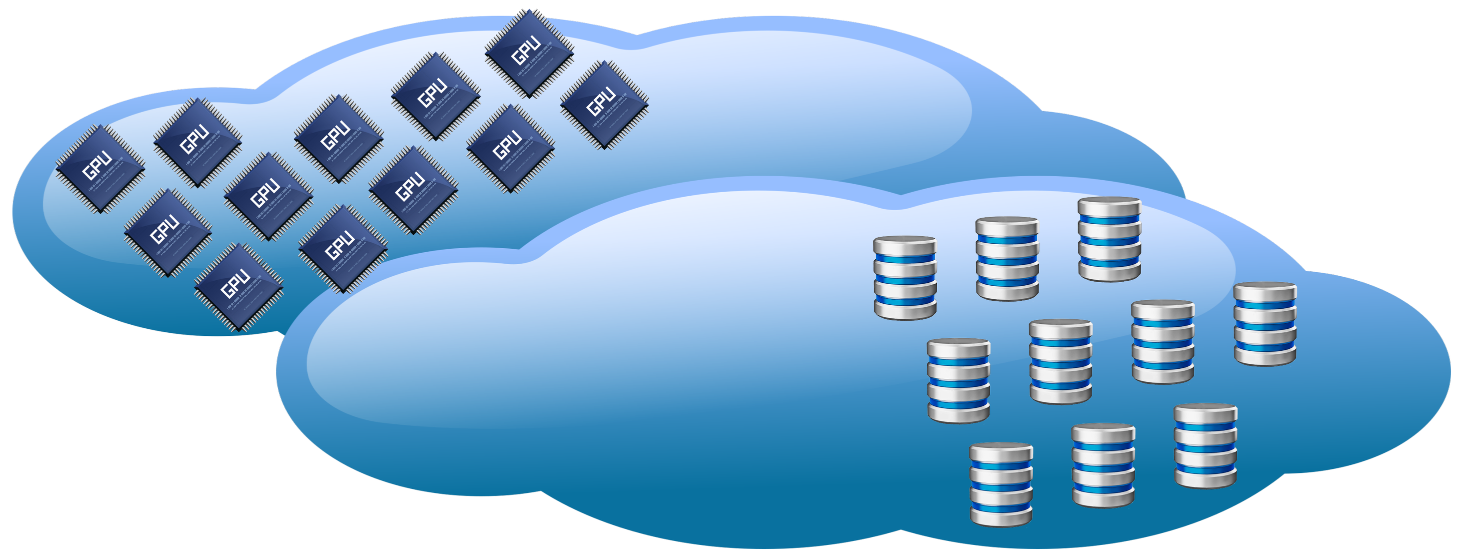
1979



2017

≤ 2050



Archival Data and Computational Power in Planetary Astronomy: Lessons Learned 1979–2016 and a Vision for 2020–2050

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A Future Data Analysis Scenario

1. A scientist has a hypothesis and wishes to test it.

2. The relevant data sets are already on the ground, having been obtained by NASA spacecraft and Earth-based facilities over a time span of many decades.

3. The scientist quickly codes up a data processing algorithm, building upon a large library of tested, documented, open-source building blocks contributed by her fellow scientists.

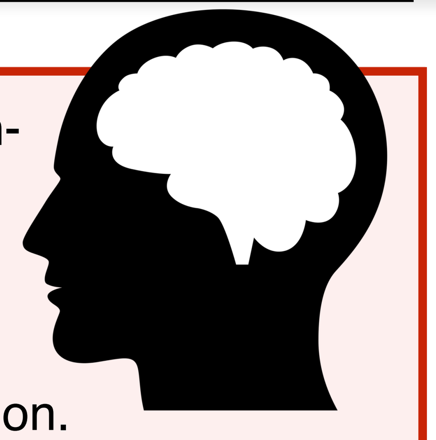
4. She prepares a virtual machine (VM) that contains the program and any relevant support files, and submits the VM to a cloud computing service.

5. An arbitrary number of instances of the VM execute in the cloud, assimilate the results, and deliver them back to her quickly.

6. Using visualization tools based on other open-source algorithms, she explores the results and reaches her conclusions.

7. She publishes her results as a journal article, plus supplemental data and VMs. Results are immediately available to the rest of the community.

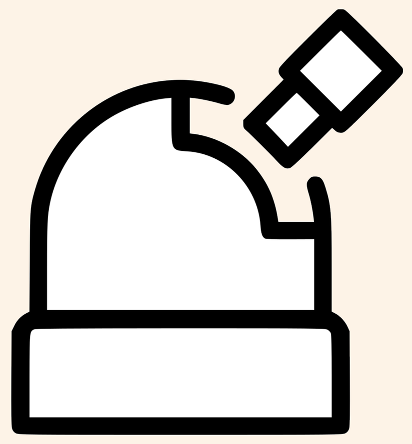
1.



- Scientific research will always be a human-centered enterprise.
  - HAL will not help us.
- Our goal should be to minimize obstacles along the path from hypothesis to conclusion.

2.

- NASA archiving must be comprehensive, including data from Earth-based telescopes, lab experiments and published theoretical models.
- All data sets must include raw and calibrated data, plus a rich and complete set of metadata.
- **Approaches:**
  - Standardize planetary metadata ("SPICE 2050"?).
  - Provide pointing geometry at pixel-scale precision or finer.
    - Hardware solution (best): Develop better spacecraft tracking and telemetry.
    - Software solution (if needed): Apply geometric reconstruction to images via pattern recognition.
  - Find a way to preserve mission software so it will continue to run forever.
    - Currently, the lifetime of any program is ≲ 10 years.
  - Archive easy-to-use derived data products (maps, etc.), when backed up by scientific publications.
  - Employ "scraping" of the literature, press release images and captions, and supplementary data from journals, to keep the archive complete.



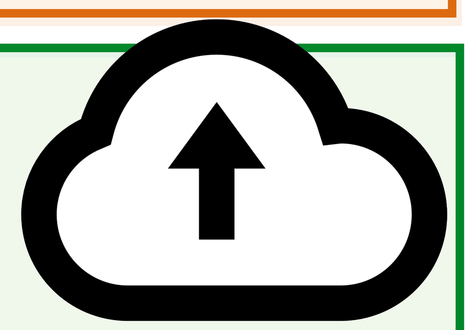
3.

- Widespread availability of open-source software will prevent NASA-funded scientists from constantly needing to "re-invent the wheel".
  - Eventually, the accumulated tools will allow most scientists to focus on research, not programming.
- **Approaches:**
  - NASA should continue to encourage the sharing of open source software by its scientists.
  - NASA should reward (and fund) scientists for well-designed, well-documented libraries.
    - Scientists have no incentive to share their tools if publications are the only metric of success.
  - We should consider identifying a limited set of "recommended" programming languages.
  - Discourage or perhaps even forbid the use of proprietary languages (e.g., IDL and Matlab).
    - Long-term costs to NASA are very high.
    - Proprietary languages cannot be used in VMs.
  - Find ways to harness the latest developments in computing, e.g., neural nets, GPU programming, and whatever else may be coming in the decades ahead.

7.

- Immediate, automatic archiving can speed up the pace of NASA discoveries, because each new result will be instantly available to the entire community.
- **Approach**:
  - Develop automated tools and templates that ensure every data set is accompanied by suitable documentation and metadata.
  - Employ intelligent "scraping" of new publications.

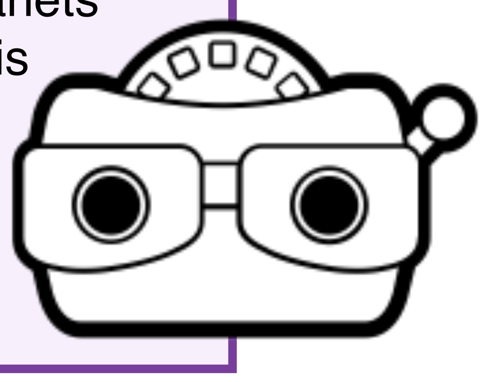
4.



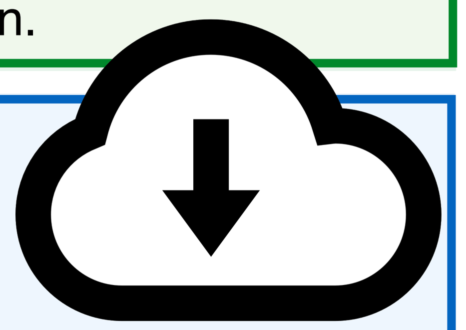
- VMs are self-contained entities holding the OS, software and support files.
  - They can be shared, executed in the cloud (in arbitrary numbers), and also used locally.
- VMs are only useful if for processing can be performed without human intervention.
- **Approaches**:
  - Ensure that all metadata is accurate enough for "blind" data processing.
  - Encourage the use of VMs as a mechanism to distribute and document analysis procedures and models.
  - Spearhead efforts to ensure that VMs can be archived and reused decades after their creation.

6.

- Data visualization is one area where planetary scientists can benefit from development going on at for-profit companies.
  - Example: "Google Earth" has now been used for "Google Mars", "Google Moon" and "Google Pluto".
- Many companies are currently investing in Virtual Reality (VR).
- **Approaches:**
  - We should encourage for-profit companies to support planets within their VR tools, noting the educational value that this support will provide to the broader public.
  - NASA should encourage and support development of open-source VR tools for the exploration and visualization of planetary data.



5.



- Cloud computing has the potential to revolutionize planetary data analysis and modeling.
  - Highly parallel problems (e.g., process every image that…) can execute very quickly.
- **Approaches**:
  - Permanently store all data and metadata within cloud services where VMs can have direct access.
  - Encourage and fund the use of cloud computing; spearhead efforts to reduce its cost.