Jet Propulsion Laboratory
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TargetWizard

Streamlining robotic operations for greater science

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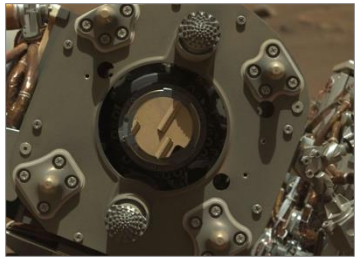
Background

- The Perseverance rover (Mars 2020) is exploring Mars's Jezero Crater, one of the best places to study the possibility of past extraterrestrial life.
- Mars 2020's abrasion drill bit cuts 5 cm patches in rocks.
- Why is abrasion important?
  - Surface exposed to weathering and radiation for billions of years
  - It's best to detect biosignatures with SHERLOC and PIXL on abrasion patch
  - Helps place observations and samples in proper geologic context

The remains of a river channel ending in a delta in Jezero Crater, an ancient Martian lake. ESA/DLR/FU-Berlin



Mars 2020's abrasion drill bit. NASA/JPL-Caltech/ASU

Abrasion patch of "Bellegarde." NASA/JPL-Caltech/ASU/MSSS

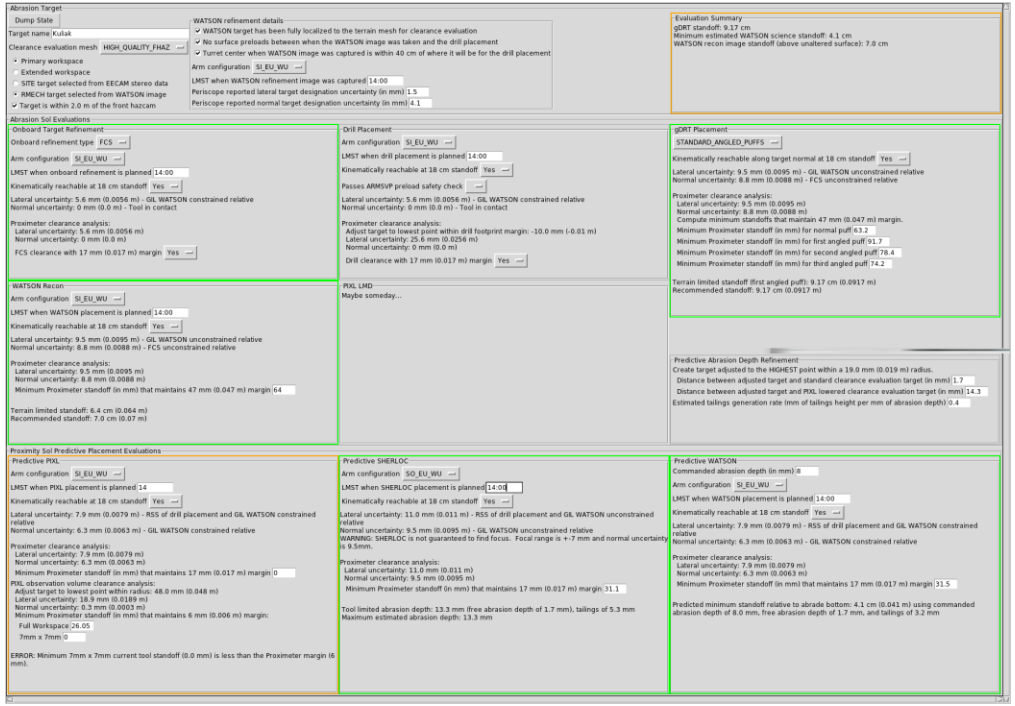
The challenge

- Scientists prefer deeper abrasions, but this puts instruments closer to terrain, which increases collision risk.
- Instruments are on a 99 lb turret at the end of a 7 ft arm and must be placed ~1 inch from surface.
- A $2.8 billion national asset is on the line if rover planners (RPs) get any of these wrong:
  - Arm placement accuracy
  - Arm deflection prediction
  - Terrain knowledge accuracy
  - Uncertainty due to thermal changes

Sol 1480 WATSON observation of abrasion patch. NASA/JPL-Caltech

Previous state of the art

- RPs must answer: what target in the workspace can be abraded the deepest, while safely placing science instruments on it?
- Guided by an extensive procedure that was turned into an interactive application



The app that guides RPs through the procedure to evaluate a single abrasion target.

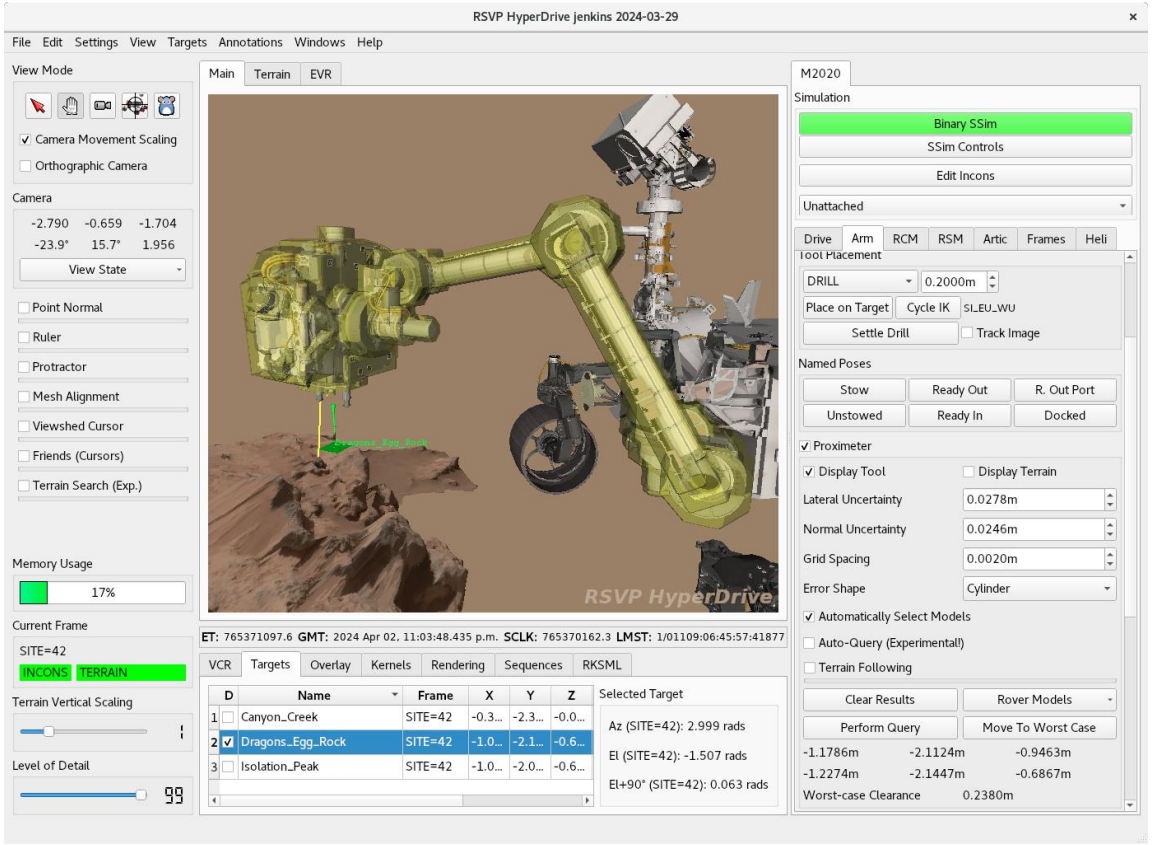
Previous state of the art

- **Process was slow:** The most experienced RPs said it took ~40 minutes to fully evaluate a target.
- **Process was error-prone:** In operations, Mars 2020 staffed two RPs to evaluate the same targets and reconcile differences in their evaluations.
- **Few RPs were knowledgeable enough** to do arm abrasion assessments
  - Refresher course for RPs on arm abrasion evaluation took 1 hr 20 m to explain how to evaluate a single target.
  - Early on, mission could only abrade when the most experienced RPs were on shift.

> *… the team could only abrade on a planning sol where two of the very few key trained people were scheduled because the assessment for the abradability… was a very unique skill.*

Jennifer Trosper, JPL Fellow and M2020 Project Manager

Previous state of the art

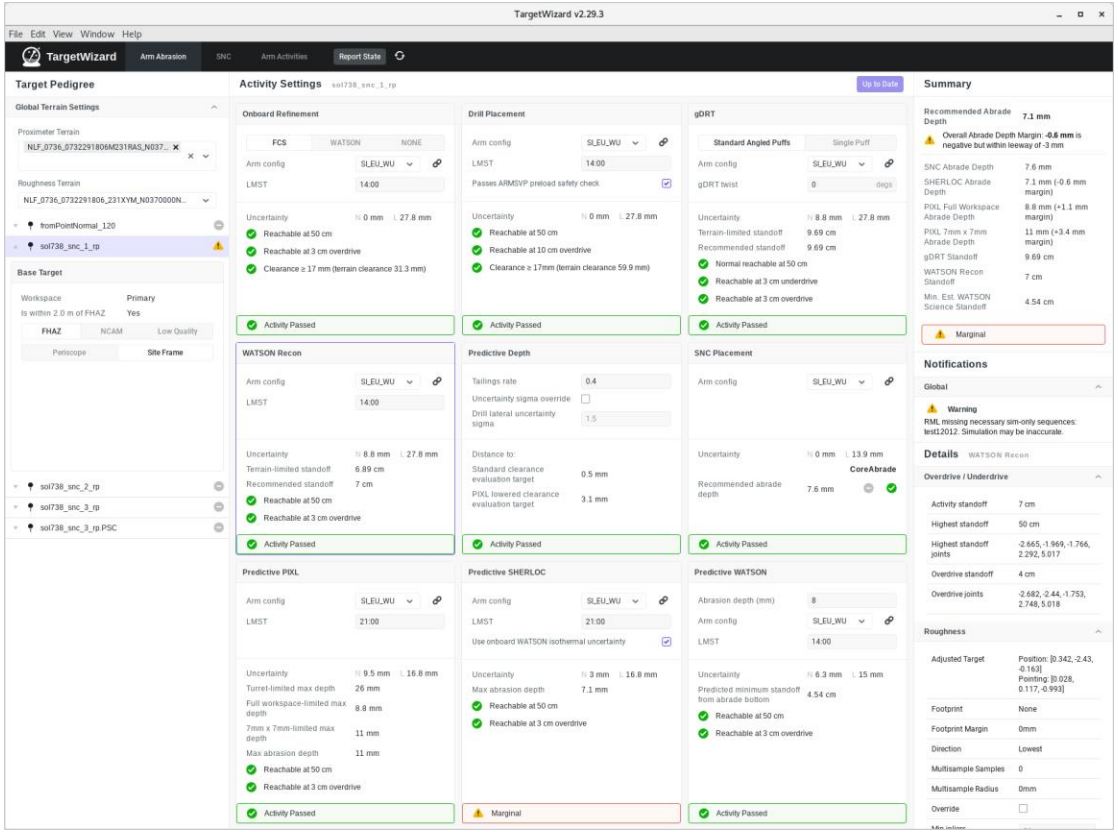


HyperDrive is an application with 20+ years of heritage. It has operated MER, MSL, Insight, and Mars 2020.

Analogy: A “Swiss Army knife” tool that allows users to perform many different analyses in one interface.

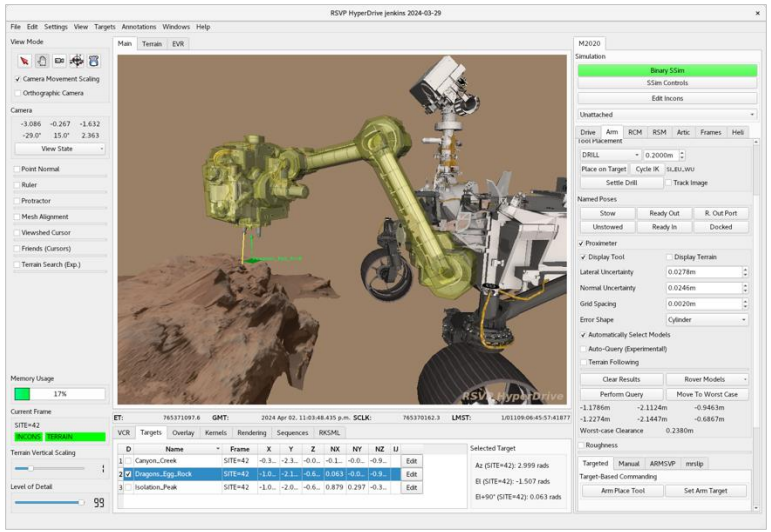
TargetWizard

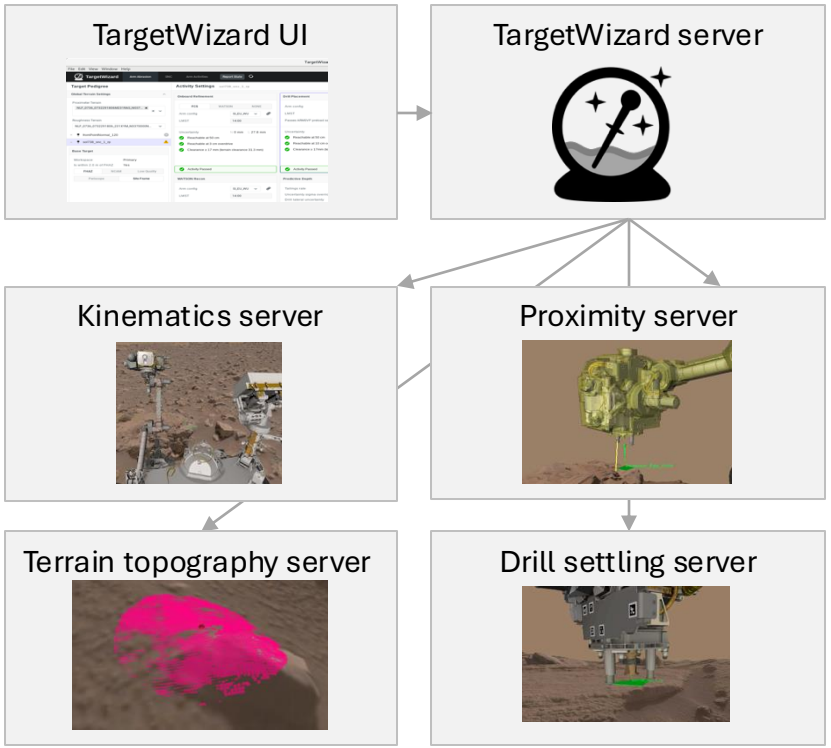
- A new robotic analysis tool to automatically evaluate abrasion targets.
- Click one button: “Compute”
- We’ll explain:
  - What it does
  - Software innovations
  - Impact on science
  - Our cost-efficient development process



Innovation #1 – Ubiquitous automation

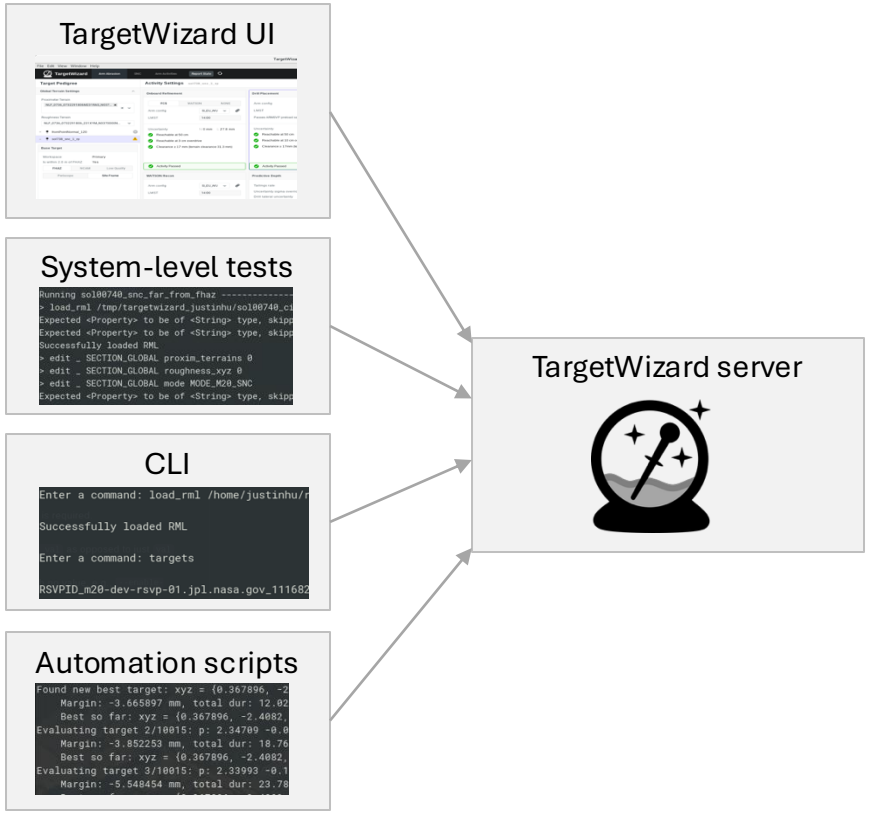
- Insight: human interaction is the slowest part
- Extracted automatable services from HyperDrive
  - Can run 10s or 100s of queries in same time that a human can make one





Innovation #1 – Ubiquitous automation

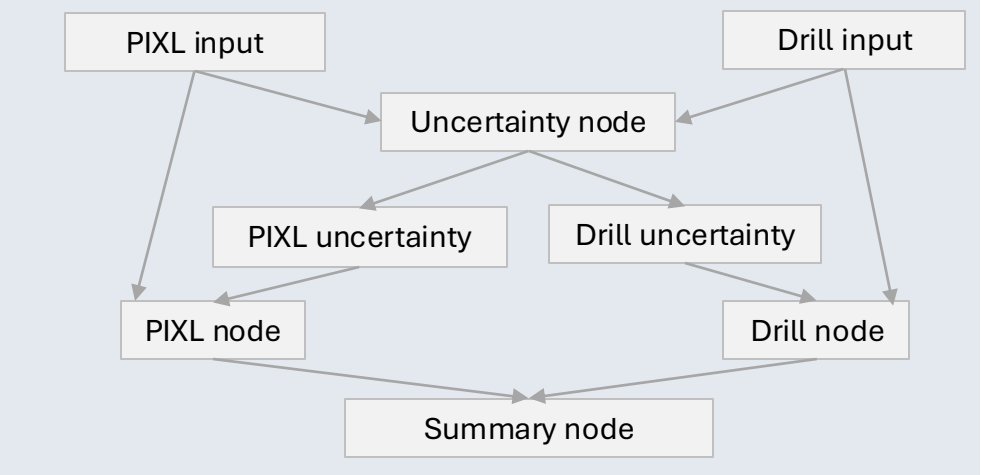
- TargetWizard is itself a service
- UI is only a view, all logic contained in server
- Benefits:
  - Automated system tests use the service the same way the user does
  - Easily replicate bugs by logging all service calls
  - Command-line client for power users
  - We can automate TargetWizard itself – more on this later



Innovation #2 – Efficient computation

- Most robotic analysis software require recomputation when an input changes
- TargetWizard structures its computation as a graph
  - When an input changes, only recompute nodes affected by the change
- Gives RPs the ability to explore different scenarios without waiting for a full recomputation.

An example subset of the computation graph.



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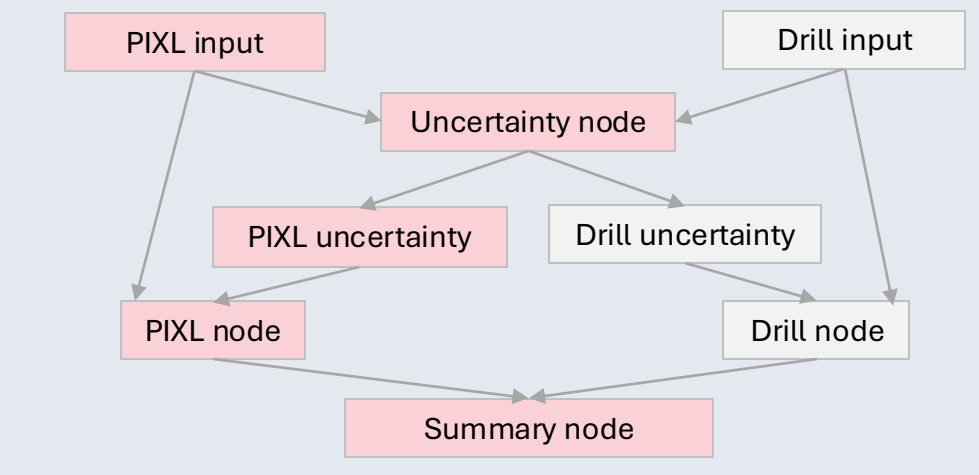
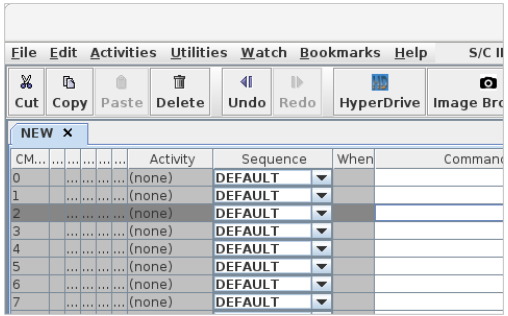
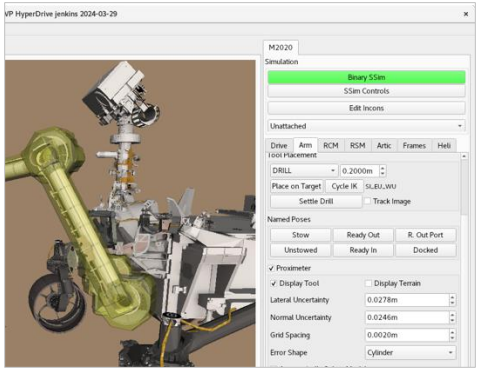
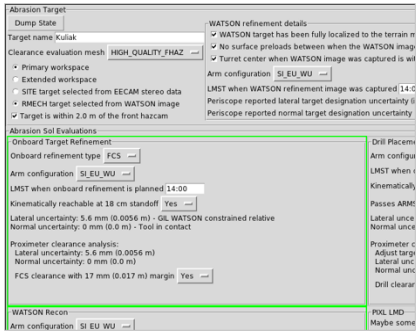
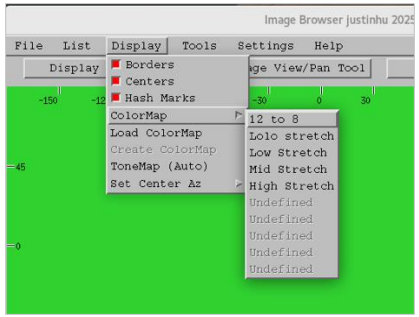


Innovation #3 – Modern GUI





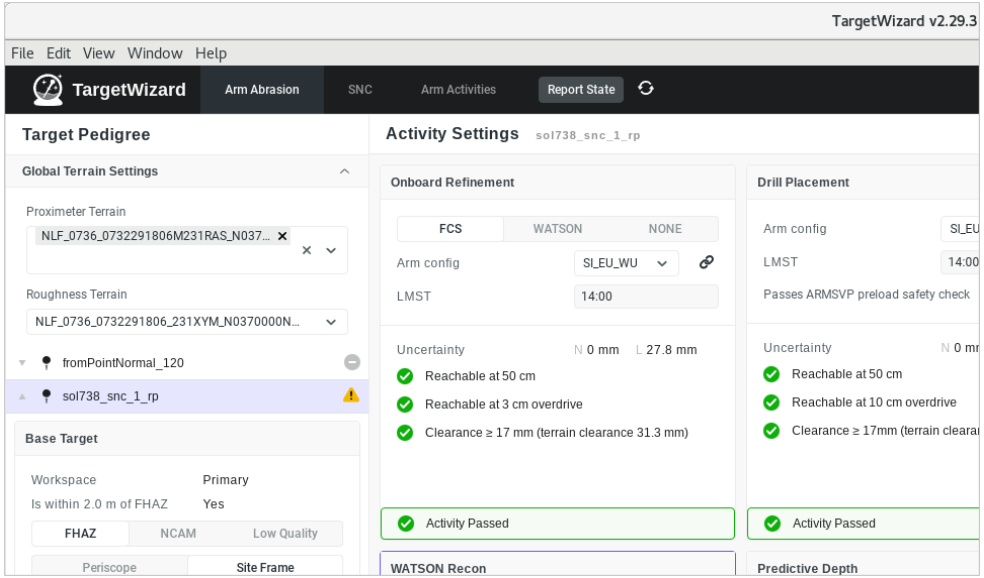




- A lot of spacecraft operations software isn't intuitive -- designed by engineers with new features added on for 20+ years.
- Legacy applications use unfamiliar GUI frameworks like Tcl/Tk, Qt, Motif, and Swing.

Innovation #3 – Modern GUI

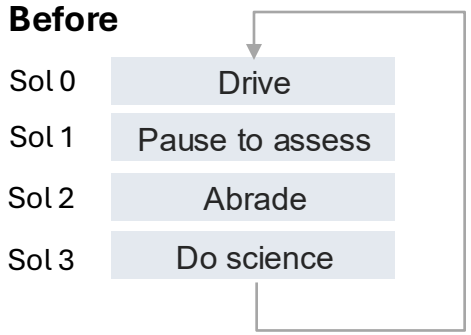
- TargetWizard is a desktop application, but uses industry-standard web technologies (React and Electron) for its UI
- Collaborated with a designer from 17x
- Uses JPL's in-house Stellar design system for spacecraft operations tools

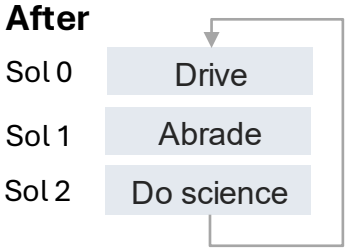


What was the impact?

Impact #1 – Sol savings

- Instead of taking 40 minutes to evaluate a single candidate target, TargetWizard takes < 15 seconds.
- This doesn't just save 40 minutes… it saves 1 day per abrasion!
  - RPs unable to assess targets within limited time budget Instead, the mission paused the rover for a day to let RPs do target assessment, which underutilized the rover
  - TargetWizard eliminates the extra day
- This alters the cadence of Mars 2020 operations, affecting ~70 people per day who operate the rover.
- More than half of all abrasions have been done with TargetWizard.





Impact #2: Personnel

- Decreased RP staffing for abrasion sols from two people to one person
- Any RP can use TargetWizard, not just the most experienced ones

> *… the team could only abrade on a planning sol where two of the very few key trained people were scheduled because the assessment for the abradability… was a very unique skill…* ***Through the development of the TargetWizard capability… this task was automated… [and] no longer dependent on which personnel were staffed.***

Jennifer Trosper, JPL Fellow and M2020 Project Manager

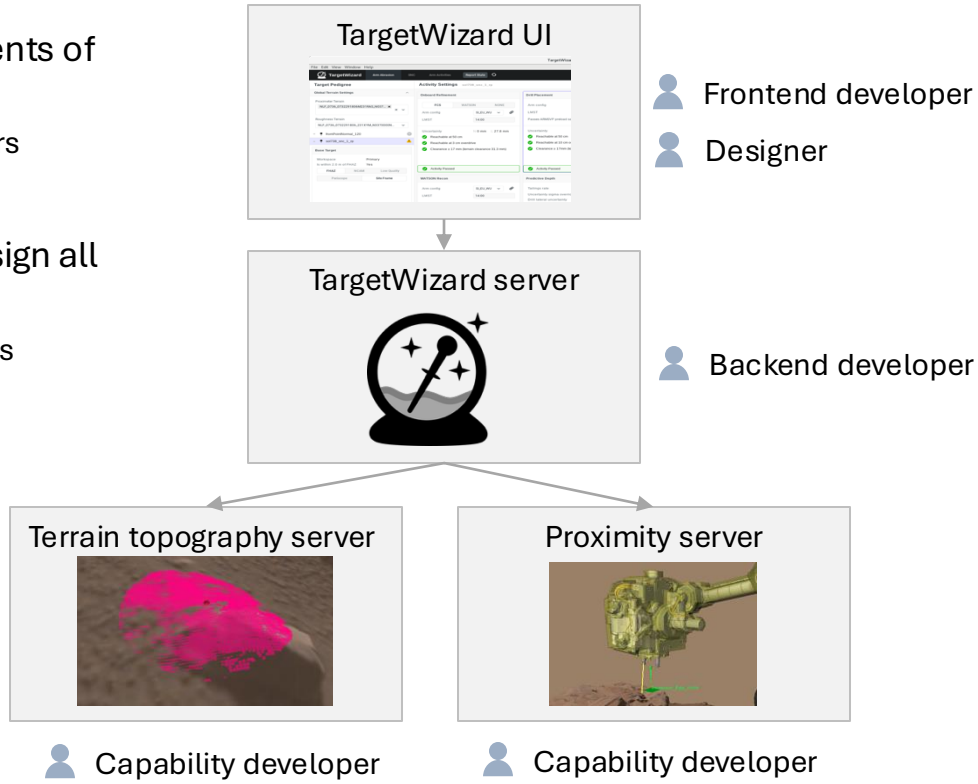
Cost-efficient development

So how much did all this cost?

- Lean development team
  - 1 backend engineer / manager
  - 1 frontend engineer
  - 1 designer
  - 2 part-time capability engineers
- From kickoff meeting to first release was ~6 months
- How?
  - Software architecture
  - State of the art developer tools
  - Quick feedback loop and ruthless prioritization

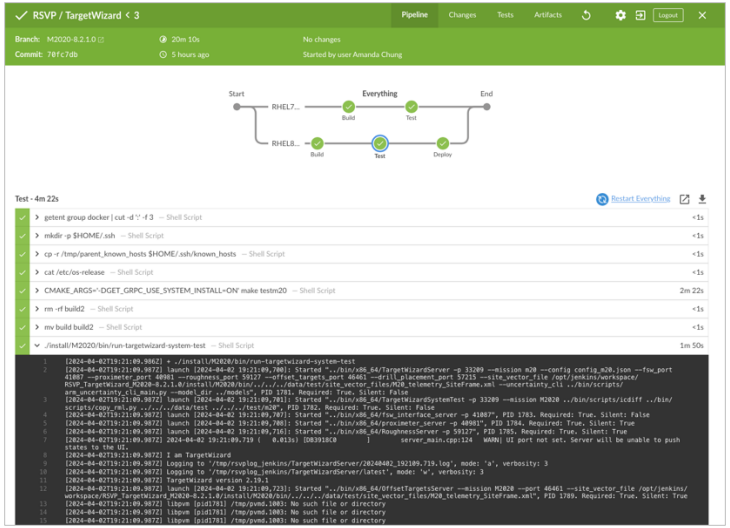
Efficiency #1 – Software architecture

- Capability engineers extracted components of RSVP into services
  - Services have been reused for other Mars operations software
- Backend, frontend, capabilities, and design all developed in parallel
  - Design by contract at service boundaries



Efficiency #2 – Developer tools

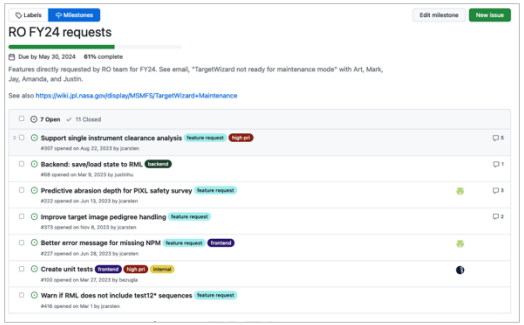
- Automated unit and system-level testing
  - System tests verify accuracy of hundreds of data points with sub-mm and sub-mrad accuracy
- Jenkins continuous integration and deployment
  - Automatically runs unit and system-level tests
  - Automatically builds and packages software
  - We automatically deploy nightly build for RPs to try
- Automatic code formatting
- Linting with clang-tidy and cppcheck



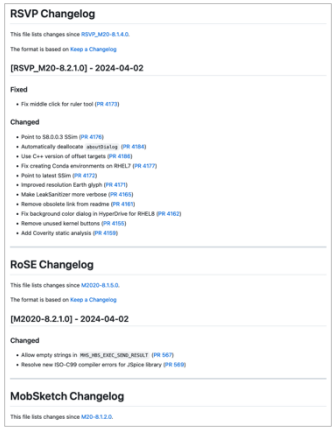
Continuous integration server automatically tests every code change and deploys a nightly build.

Efficiency #3 – Rapid feedback

- Rapid, low-overhead development process
  - Semi-monthly developer/customer meetings to give updates and get feedback
  - Issues prioritized, assigned, and tracked in GitHub
  - Developers solve issues and merge to master
  - CI/CD deploys changes to nightly build
  - Repeat
- Monthly official releases
  - Release documentation automatically generated
  - Customers do independent acceptance testing



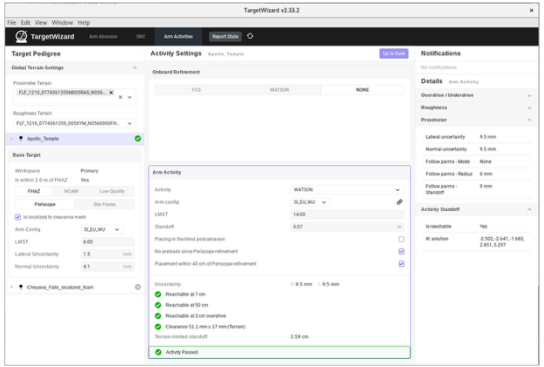
GitHub project tracker



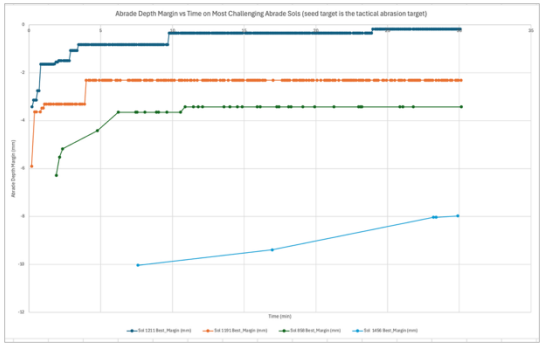
Release documentation

Expanded scope

- TargetWizard has since developed significant new features since its initial release
  - Sampling and Caching (SNC) mode: SNC engineers use TargetWizard to do their assessments for arm abrasions
  - Arm activities mode: RPs use TargetWizard near daily to evaluate safety of individual arm activities
- Newly released meta-automation: AutoTarget
  - AutoTarget program runs in background and uses TargetWizard API to find better candidate targets
  - Early studies show AutoTarget finds targets better than human-selected targets after about 10 min
  - Targets are 3 mm deeper on average, providing greater science output and greater likelihood of success on difficult terrains



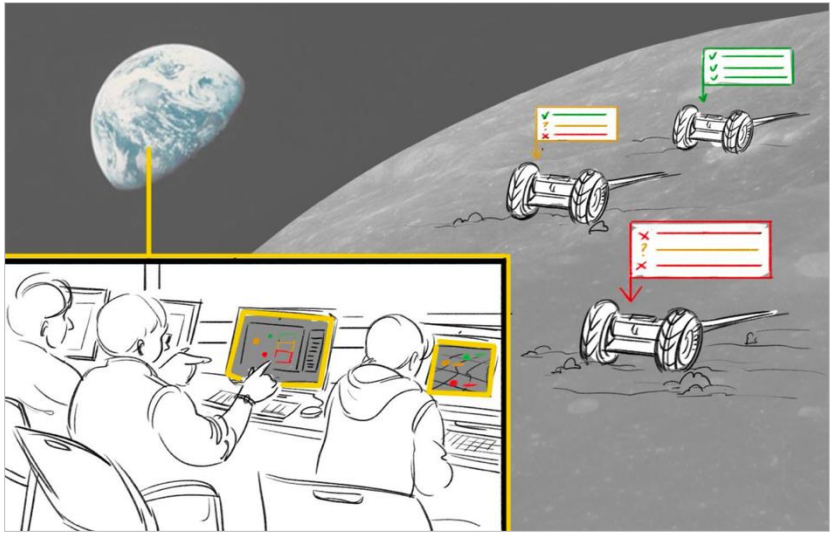
A screenshot of TargetWizard's arm activities mode.



A chart showing AutoTarget finding abrade depth improvements over time for past challenging scenarios.

Future work

- Currently developing TargetWizard for Curiosity rover
- TargetWizard is designed to be mission-independent and can be applied to any surface robotics mission
- TargetWizard redefines how spacecraft operations should work
- Future missions could include autonomy that inherits from TargetWizard



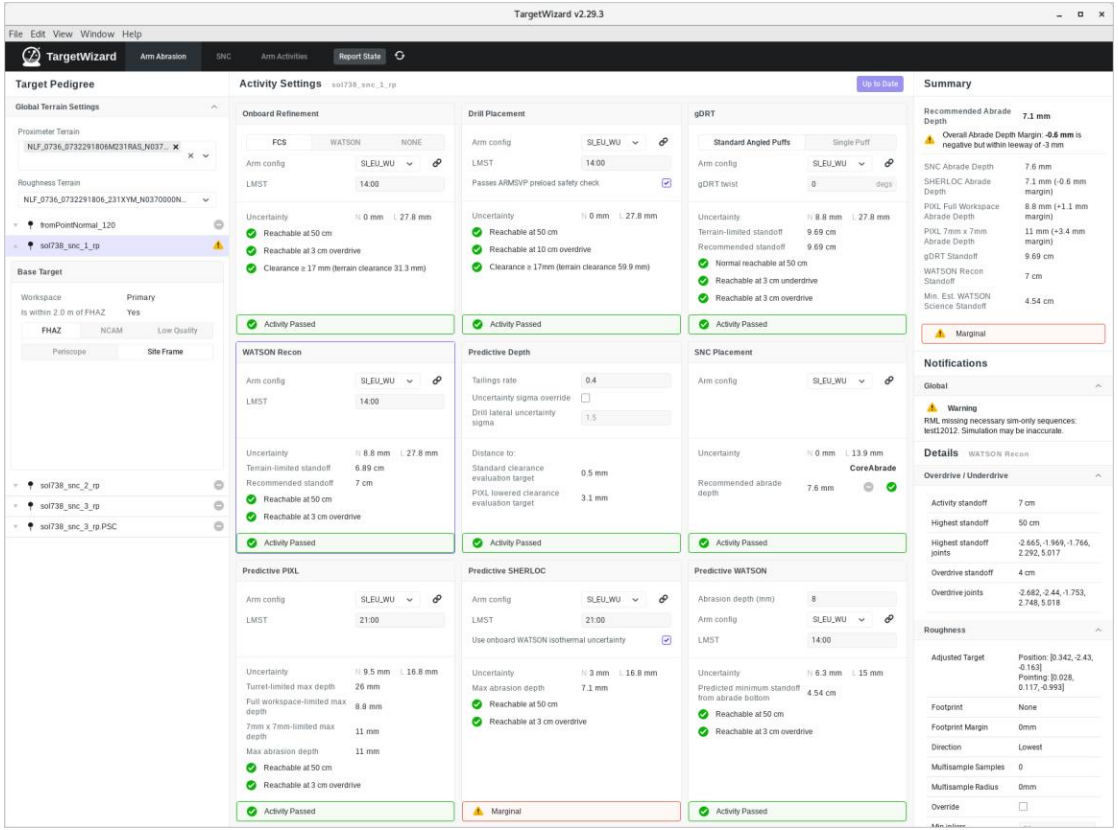
Conclusion

- TargetWizard dramatically increases science return and reduces cost.
- It demonstrates software innovations and cost-saving development processes.
- TargetWizard serves as a model for how JPL/NASA can tackle big challenges efficiently.

[TargetWizard] has resulted in tangible future savings of more than a month of mission time that can now be used instead to access more diverse and high value science and sampling targets.

Kathryn Stack Morgan, Mars 2020 Deputy Project Scientist

Thank you!



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