



Completion of NASA's Laser Communications Relay Demonstration (LCRD) Experiment Program

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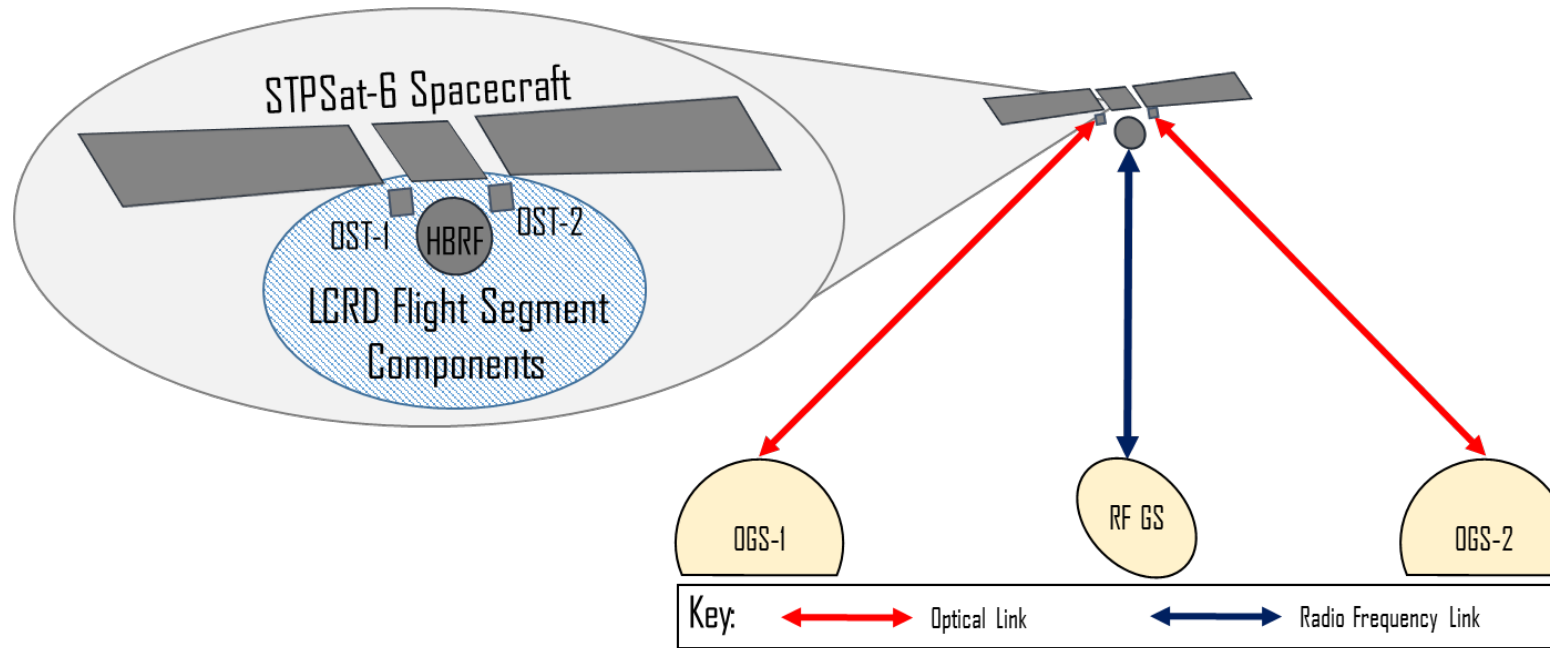


Outline



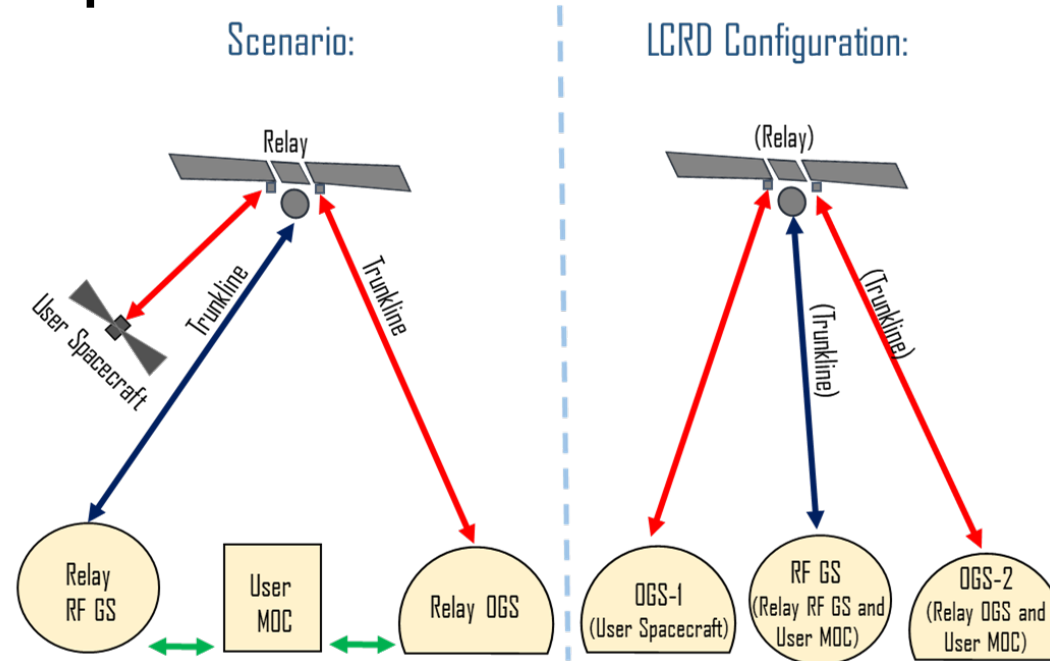
- Introduction
- Experiment and Availability Statistics
- ILLUMA-T Experiments
- Conclusions
- Acknowledgments

LCRD Mission Experiment Architecture



- The Laser Communications Relay Demonstration (LCRD) launched in December 2021 and experiments began June 2022
- Flight segment is on board the Space Test Program Satellite-6 (STPSat-6) spacecraft in geosynchronous Earth orbit (GEO)
 - Two optical space terminals (OST), OST1 and OST2 (maximum rates of 1.244 Gbps)
 - High-bandwidth Radio Frequency (HBRF) terminal
 - Data switch
- The ground segment
 - Optical Ground Station 1 (OGS-1) in Table Mountain, California
 - Optical Ground Station 2 (OGS-2) in Haleakalā, Hawaii
 - Radio frequency ground station (RF GS) in White Sands, New Mexico

Relay Service Provider Experiments and Operational Demonstrations



- Fundamental experiments characterizing system and link performance continue
 - Collecting data to refine models
 - Ongoing operational experience
- A series of experiments have been defined to go beyond link investigations and operate the system as a lasercom relay service provider

Statistics: Experiment Sessions and Availability



LCRD Experiment Sessions												
Data Time Span						Experiment Session Success						
						Scheduled	Session Results (Counts)			Session Results (Pct)		
Time Frame	First Date	Last Date	First DOY	Last DOY	Calendar Days		NS Weather	NS Technical	Successful	NS Weather	NS Technical	Successful
Previous Summary Reported	6/10/22	11/26/23	161	330	535	1418	280	306	832	20%	22%	59%
Update Period Summary	11/27/23	7/14/24	331	196	231	803	98	152	553	12%	19%	69%
Total Since Operations Started (6/10/22)	6/10/22	7/14/24	161	196	766	2,221	378	458	1,385	17%	21%	62%

Element	Availability 6/10/22 – 11/26/23	Availability 11/27/23 – 7/14/24	Total Availability 6/10/22 – 7/14/24
Payload	99.3%	100.0%	99.5%
OGS-1	57.8%	76.0%	65.0%
OGS-2	40.5%	85.1%	56.6%
RF Ground Station	99.2%	97.4%	98.7%

- Experiment success rate and availability driven by ground station availability
- Flight systems have been the most reliable parts of the system
- Meeting operational availability requirements for future systems will require more than two ground stations and ground stations built for operational use (not demonstrations)

ILLUMA-T: First LEO User of LCRD



LCRD at GEO

Launched Dec 7, 2021



ILLUMA-T on ISS at LEO

Launched Nov 9, 2023

Jettisoned Jun 29, 2024

ILLUMA-T

(Integrated LCRD LEO User Modem and Amplifier Terminal)

Develop an optical communications user terminal to demonstrate data transfer between low Earth orbit and the ground through a geosynchronous relay

- Provides 1.2 Gbps return link for ISS
- Provides 50 Mbps/155 Mbps forward link
- Demonstrates optical relay utility with LCRD



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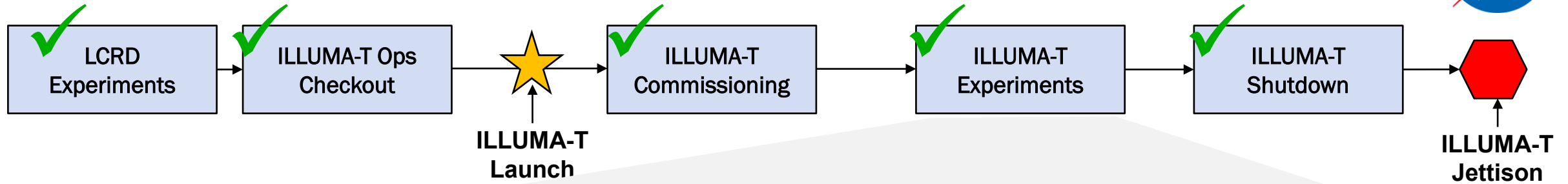
JAXA
宇宙航空研究開発機構
Japan Aerospace Exploration Agency



Goddard
SPACE FLIGHT CENTER

JPL

Experiments Overview



Baseline Performance

- 9 of 9 experiments completed

Exp. ID	Exp. Name	Ground Resource	Status
B01	Forward Link Rates*	OGS1	Complete
B02	Return Link Rates*	OGS1	Complete
B03	LT to LCRD Payload & Back	Space Only	Complete
B06	RF State T4B	Space Only	Complete
B07	Return Link 1.244 Gbps in T4B	OGS1	Complete
B08	Return Link 1.244 Gbps in T4A*	OGS1	Complete
B10	Optical from LT to LCRD & RF from LCRD to Ground	PGLT	Complete
B11	Return Ethernet*	OGS1	Complete
B12	Forward Ethernet*	OGS1	Complete

Exploring Margins

- 12 of 17 experiments completed
- 2 exps completed, analysis pending
- 3 exps deemed not relevant

Exp. ID	Exp. Name	Ground Resource	Status
E001	Forward Link Delay Correlation*	OGS1, OGS2	Analysis in progress
E002	Return Link Delay Correlation*	OGS1, OGS2	Analysis in progress
E003	Forward Link Delay Correlation*	Space Only	Complete
E004	Return Link Delay Correlation*	Space Only	Complete
E005	Return Link Delay Correlation*	Space Only	Complete
E006	Return Link Delay Correlation*	Space Only	Complete
E007	Return Link Delay Correlation*	Space Only	Complete
E008	Return Link Delay Correlation*	Space Only	Complete
E009	Return Link Delay Correlation*	Space Only	Complete
E010	Return Link Delay Correlation*	Space Only	Complete
E011	Return Link Delay Correlation*	Space Only	Complete
E012	Return Link Delay Correlation*	Space Only	Complete
E013	Return Link Delay Correlation*	Space Only	Complete
E014	Return Link Delay Correlation*	Space Only	Complete
E015	Return Link Delay Correlation*	Space Only	Complete
E016	Return Link Delay Correlation*	Space Only	Complete
E017	Return Link Delay Correlation*	Space Only	Complete
E018	Return Link Delay Correlation*	Space Only	Complete
E019	Return Link Delay Correlation*	Space Only	Complete
E020	Return Link Delay Correlation*	Space Only	Complete

Network/Data Usage Baseline Experiments

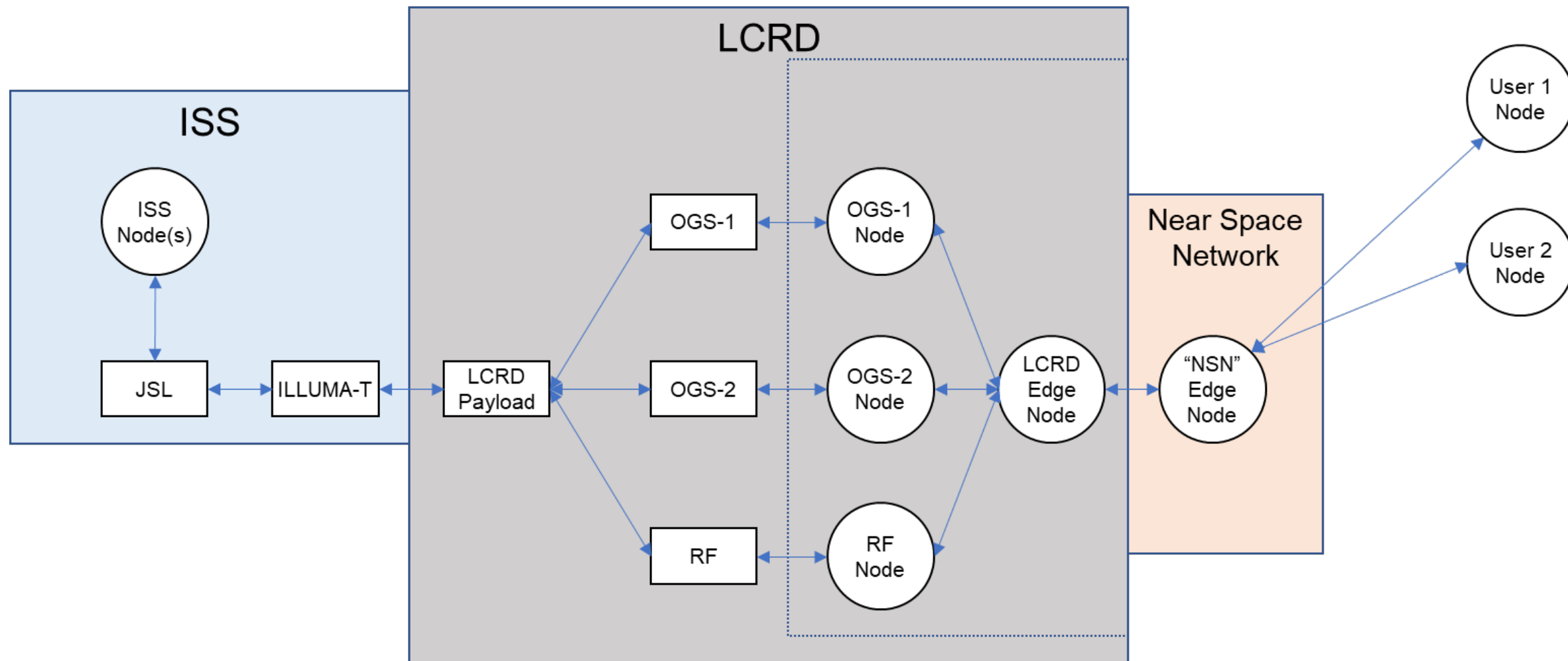
- 4 of 4 experiments completed

Phase	Exp. ID	Exp. Name	Ground Resource
Baseline	NB01	IP connectivity with WSC	OGS1
Baseline	NB02	IP application with WSC	OGS1
Baseline	NB03	DTN connectivity with WSC	OGS2
Baseline	NB04	DTN application with WSC	OGS2
Extended	NEM01	IP Connectivity with NSN Edge Node	OGS1, OGS2, PGLT
Extended	NEM02	IP Application with NSN Edge Node	OGS1, OGS2, PGLT
Extended	NEM03	DTN Connectivity with NSN Edge Node	OGS1, OGS2, PGLT
Extended	NEM04	DTN Application with NSN Edge Node	OGS1, OGS2, PGLT
Extended	NEM05	IP Application with NSN User	OGS1, OGS2, PGLT
Extended	NEM06	DTN Application with NSN User	OGS1, OGS2, PGLT
Extended	NEM07	Network Data Flows with Handovers	OGS1, OGS2, PGLT
Extended	NEM08	Low Latency IP Applications	OGS1, OGS2, PGLT
Extended	NEM09	Multiple simultaneous data flows and endpoints	OGS1, OGS2, PGLT

Extended Functionality (Data/Network services)

- 9 of 9 experiments completed

LCRD/ILLUMA-T Networking Experiment Architecture



- DTN over optical
- Architecture proven
- ISS send/receive without the MCC
- ISS connected to field center
- ISS connected to aircraft

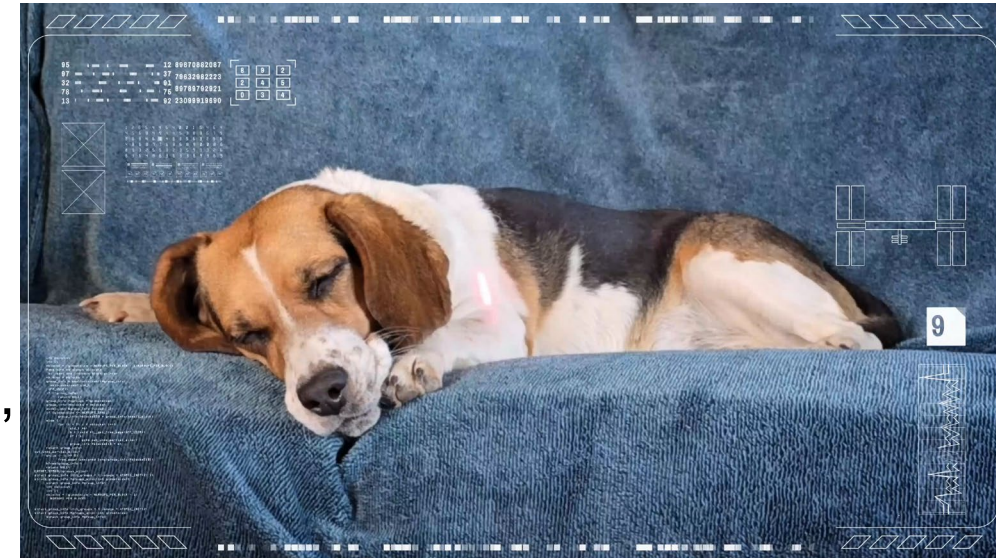
- 980Mbps
- BPv7
- BPv7
- BPv7
- Custody
- Handovers

- 4k streaming from ISS
- 4k streaming to ISS
- ISS→aircraft streaming
- Aircraft→ISS streaming
- Live streaming

Conclusions



- Following the completion of the two-year LCRD experiment program, the LCRD project has entered an extended experiment phase
- Future experiments will include the ongoing characterization of link performance in relation to atmosphere and weather conditions, additional operational and networking scenarios, and demonstrations with other ground-based terminals.
- Use of an on-orbit system allows demonstrations of developing laser communication terminal technologies and ground systems.
- The inclusion of networking expands the possible set of experiments to experiments concerning space communications architectures.
- Future LCRD experiments will continue to identify and demonstrate methods for optimizing the performance of networking and laser communications links within scenarios analogous to future applications, such as lunar science orbiters, lunar relays, and Earth observation satellites.





Questions?

LCRD and ILLUMA-T are both projects under the NASA Space Communications and Navigation program.

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