National Aeronautics and Space Administration

Efficient Probabilistic Diagnostics for Electrical Power Systems

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Overview

Electrical Power Systems: Accidents and Incidents

•The Electric Propulsion Space Experiment (ESEX) mission, launched and operated in early 1999, ended prematurely when the spacecraft experienced a *catastrophic battery failure*.

•On January 14 2005, an Intelsat operated communications satellite suffered a total loss after a sudden and unexpected *electrical power system anomaly*. The failure was likely the result of a high current event in the battery circuitry triggered by an electrostatic discharge.

•A *battery failure* occurred on the Mars Global Surveyor, which last communicated with Earth on November 2, 2006. A software error oriented the spacecraft to an angle that over-exposed it to sunlight, *causing the battery to overheat*.

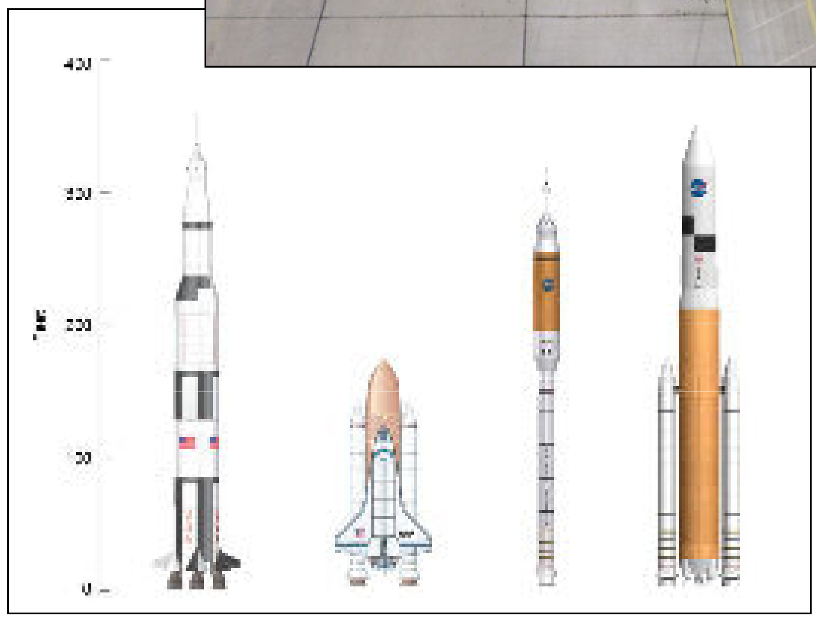
•On September 2, 1998, Swissair 111 crashed into the Atlantic Ocean. It was later determined that *short-circuited wires* could have led to a fire.

•On January 7 2008, a Boeing 747 *lost main power* on its descent into Bangkok, and had to use its battery backup.

Probabilistic Diagnostics at NASA

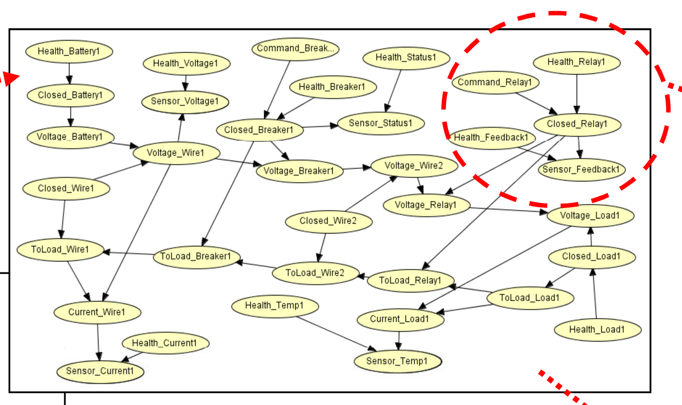
•Diagnostic challenges at NASA:
- *Complex systems*, large state spaces
- *Uncertainty* - components and sensors may fail
- *Resource-bounds* – real time requirements
- Computationally *hard problems*

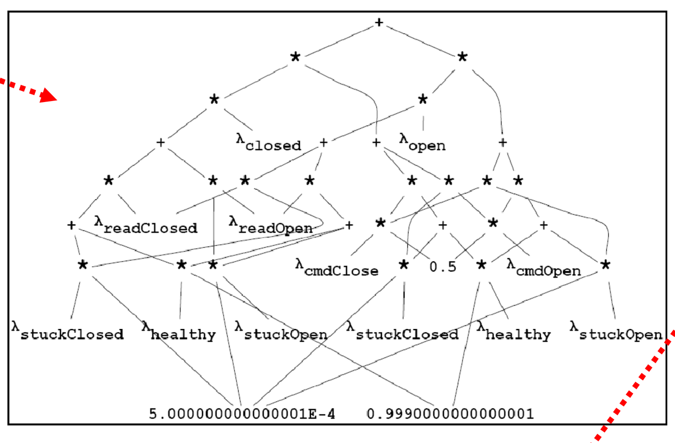
•Probabilistic diagnosis in ADAPT electrical power system:
- Auto-generation of Bayesian network
- Compilation of Bayesian network to real-time arithmetic circuit
- Speed: Means less than 1 millisecond (in software!) for ADAPT
- Predictability: Small standard deviation



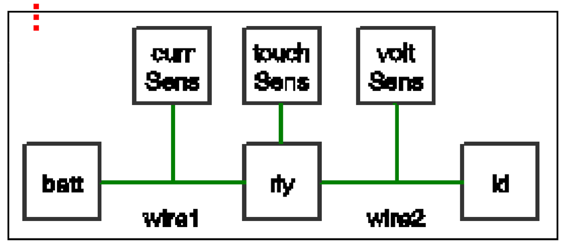
Methodology

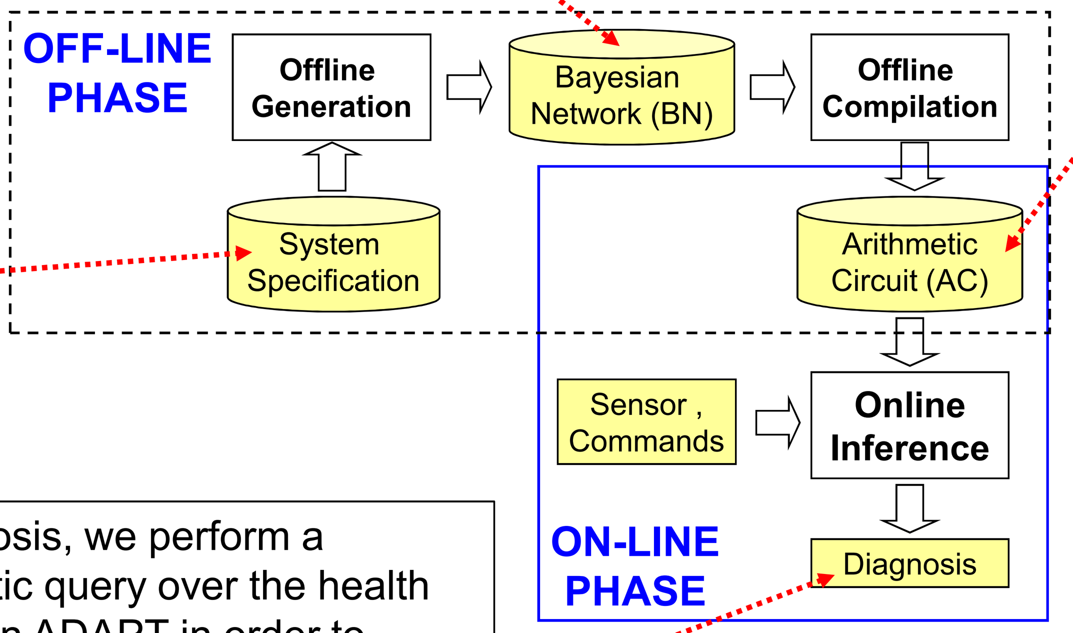
Each ADAPT health variable (of which there are over 100 currently) has at least two states (healthy and faulty), thus admitting the diagnoses of more than 2^100 instantiations of health variables.





Battery1	: battery	: 0.0005;
Wire1	: wire	: 0.0000 : Battery1;
Voltage1	: sensorVoltage	: 0.0005 : Wire1;
Current1	: sensorCurrent	: 0.0005 : Wire1;
Breaker1	: breaker	: 0.0005 : Wire1;
Status1	: sensorTouch	: 0.0005 : Breaker1;
Wire2	: wire	: 0.0000 : Breaker1;
Relay1	: relay	: 0.0005 : Wire2;
Feedback1	: sensorTouch	: 0.0005 : Relay1;
Load1	: load	: 0.0005 : Relay1;
Temp1	: sensorCurrent	: 0.0005 : Load1 ;





For diagnosis, we perform a probabilistic query over the health variables in ADAPT in order to diagnose which components and/or sensors are in non-healthy state(s).

Bayesian Networks and Arithmetic Circuits are promising probabilistic approaches to performing on-board vehicle health monitoring. We are working on methods to do V&V and certification for real-time use of these techniques in mission-critical NASA applications.

Publications:

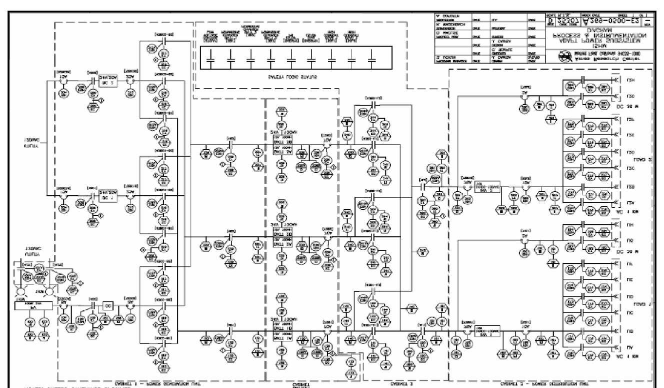
• O. J. Mengshoel, A. Darwiche, K. Cascio, M. Chavira, S. Poll, and S. Uckun (2008). “Diagnosing Faults in Electrical Power Systems of Spacecraft and Aircraft.” Twentieth Innovative Applications of Artificial Intelligence Conference (IAAI-08), Chicago, IL, July 2008.
• O. J. Mengshoel, M. Chavira, K. Cascio, S. Poll, A. Darwiche, and S. Uckun, “Probabilistic Model-Based Diagnosis: An Electrical Power System Case Study”, Submitted to IEEE Transactions on Systems, Man and Cybernetics, Part A, 2008.
• O. J. Mengshoel, A. Darwiche, and S. Uckun, “Sensor Validation using Bayesian Networks”, In Proc. of the 9th International Symposium on Artificial Intelligence, Robotics, and Automation in Space (iSAIRAS-08), Los Angeles, CA, 2008.

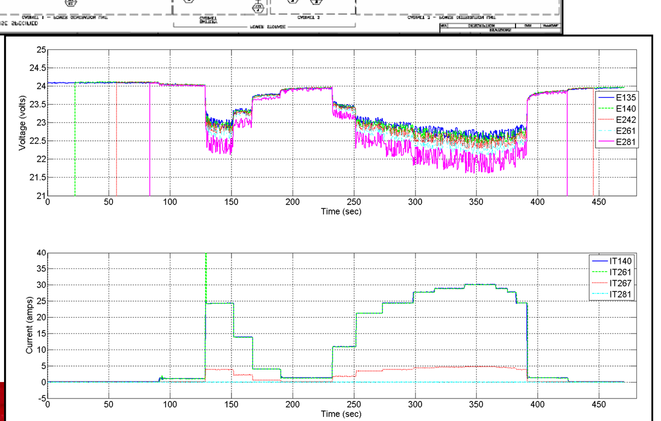
Web Sites:

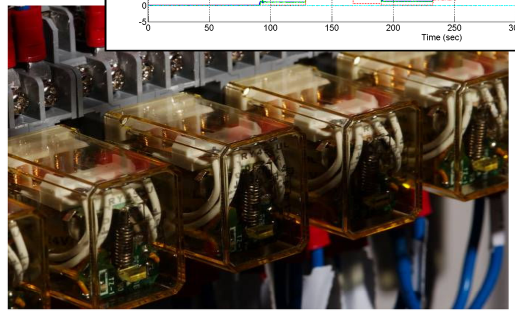
•http://ti.arc.nasa.gov/project/pca/
•https://dashlink.arc.nasa.gov/
•http://reasoning.cs.ucla.edu/
•http://www.cs.ucla.edu/~darwiche/

Results

ADAPT Testbed







Experiments with Real-World Data

ID	Faults Inserted in ADAPT	Most Probable Diagnosis - Computed	Match
304	Relay EY260 failed open	*Health_relay_ey260_cl = stuckOpen*	Yes
305	Relay feedback sensor ESH175 failed open	*Health_relay_ey175_cl = stuckOpen*	Yes
306	Circuit breaker ISH262 tripped	*Health_breaker_ey262_op = stuckOpen*	Yes
308	Voltage sensor E261 failed low	*Health_e261 = stuckVoltageLo*	Yes
309	Battery BATT1 voltage low	*Health_battery1 = stuckDisabled*	Yes
310	Inverter INV1 failed off	*Health_inv1 = stuckOpen*	Yes
311	Light sensor LT500 failed low	*Health_lt500 = stuckLow*	Yes
441	Relay EY160 stuck open Big fan ST515 stuck at 0 RPM	*Health_relay_ey160_cl = stuckOpen*	Partly
442	Current sensor IT261 noise StdDev = 5 Relay feedback sensor ESH172 stuck at 0 Current sensor IT140 stuck at 100	*Health_it261 = stuckCurrentHi* *Health_esh172 = stuckOpen*	Partly
443	Current sensor IT281 drift slope = 2 Relay EY244 stuck closed Big fan ST516 stuck at -10 RPM	*Health_it281 = stuckCurrentHi* *Health_relay_ey244_cl = stuckClosed*	Partly
445	Voltage sensor E235 stuck at 0.3 Relay feedback sensor ESH344A stuck closed Inverter INV2 failed off	*Health_e235 = stuckVoltageLo* *Health_relay_ey344_cl = stuckClosed* *Health_inv2 = stuckOpen*	Partly
447	Voltage sensor E161 failed low Current sensor IT167 failed low	*Health_e161 = stuckVoltageLo* *Health_it167 = stuckCurrentLo*	Yes
449	Voltage sensor E140 failed low Voltage sensor E161 failed low	*Health_e140 = stuckVoltageLo* *Health_e161 = stuckVoltageLo*	Yes
450	Inverter INV1 failed off Big fan ST515 stuck at 600 RPM	*Health_inv1 = stuckOpen* *Health_fan1_speed_st515 = stuckMid*	Partly
451	Relay EY171 failed open Light sensor LT500 failed low	*Health_relay_ey171_cl = stuckOpen* *Health_lt500 = stuckLow*	Yes
452	Light bulb TE500 failed off Temperature sensor TE501 failed low	*Health_load170_bulb1 = stuckDisabled*	Partly

Experiments with Simulated Data

Inference Time (ms)	MPE		Marginals	
	VE	ACE	CTP	ACE
Minimum	17.25	0.1967	8.527	0.4934
Maximum	38.45	2.779	54.51	5.605
Median	17.63	0.1995	9.204	0.5624
Mean	17.79	0.2370	10.02	0.6981
St. Dev.	1.513	0.2137	4.451	0.6669

- Comparison between Arithmetic Circuit Evaluation (***ACE***), Variable Elimination (***VE***) and Clique Tree Propagation (***CTP***)
- Main conclusions:
  - All three inference algorithms are quite efficient, thanks to auto-generation algorithm
  - ACE substantially outperforms VE (for MPE) and CTP (for marginals), both in Mean and St. Dev.

Experiments were performed on a PC with an Intel 4 1.83 Ghz processor, 1 GB RAM, and running Windows XP. Inference times (in milliseconds) are averages over 200 evidence sets.

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