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Autonomy, Learning Algorithms, and the School Bus: Some Thoughts from a Signal Processor

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About Quantum Signal

- Quantum Signal (QS) is a small, privately owned advanced R&D engineering company and University of Michigan spinoff
- QS develops advanced, intuitive mobile robotic software systems and components
- Focus on semi-autonomy, ease of use, robustness, and perceptual awareness
- Many DoD programs → growing technology base
- Have researched and developed algorithms of almost every shape and size to solve many challenges
- Headquartered in a 42k sq. ft. historic (1930) school in downtown Saline, Michigan
- Forty staff and growing

Algorithms are changing the world…

- Searching for information
- Predicting the weather
- Cooking your food
- Investing your money
- Telling you what to buy
- Telling you what to watch
- Helping detect and diagnose your illness
- Helping you drive

There is almost no area that has not or will not be touched by the application of math-based technology

Before “Big Data”…
Before “Machine Learning”…
Before “Deep Learning”…

We called it signal processing!

Autonomy is all one big nasty signal processing issue

- Intelligent vehicles revolve around perception and control

- Extract useful information from noisy or non-ideal data
  - The very definition of signal processing!

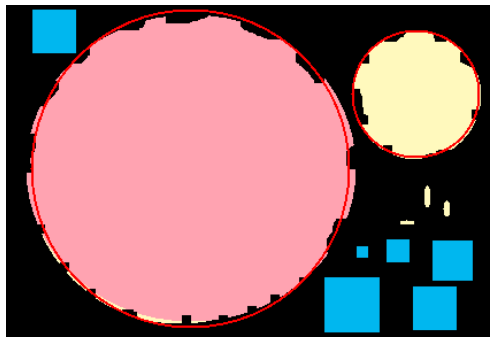
- LIDARs, cameras, etc. – perception systems follow basic process:

- *Main challenge: how do we build robust algorithms*
  - Extract what we want, and never miss
  - Ignore unwanted signals and interference

- Given the breadth of the autonomy problem, this is very, very hard

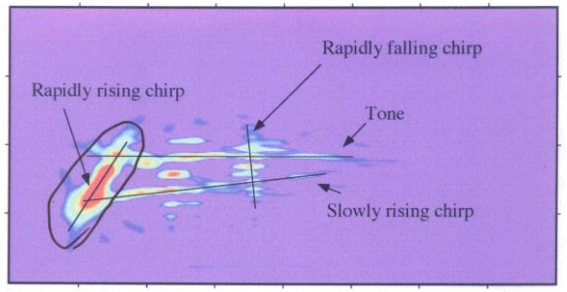
Image processing approaches

- "Computer science" approach
  - Build algorithms that follow logical, human-intuitive, codable methods
  - Find shapes, edges, etc.
  - Highly desirable, but often only works on the cleanest, most well represented data

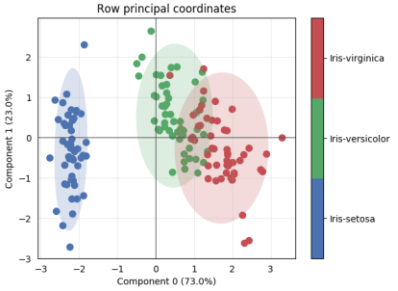


http://www.aforgenet.com/articles/shape_checker/

- "Signal processing" approach
  - Build algorithms to filter and characterize signals, extract logical curated "human relatable" features, and measure/classify as desired
  - Domain transformations typically key to characterizations, feature identification
  - Highly desirable if you can make it work – effectively first-principles approach

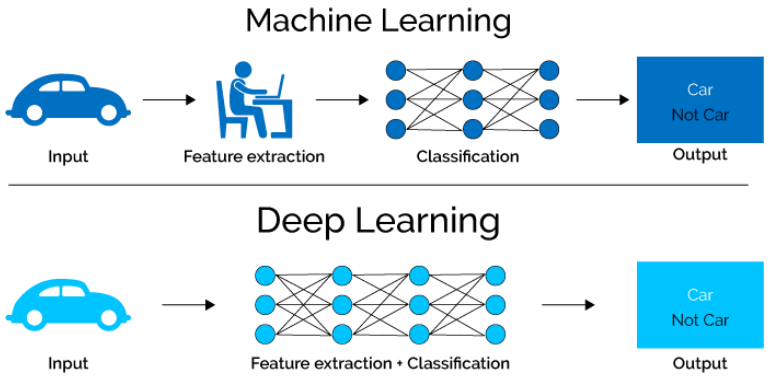


- "Statistical signal processing" approach
  - Similar to other signal processing, sans the logical curated features
  - Use statistical methods to extract features that produce desirable classifications
  - Can be extremely powerful, if non-intuitive



Solutions are a “Mash Up”

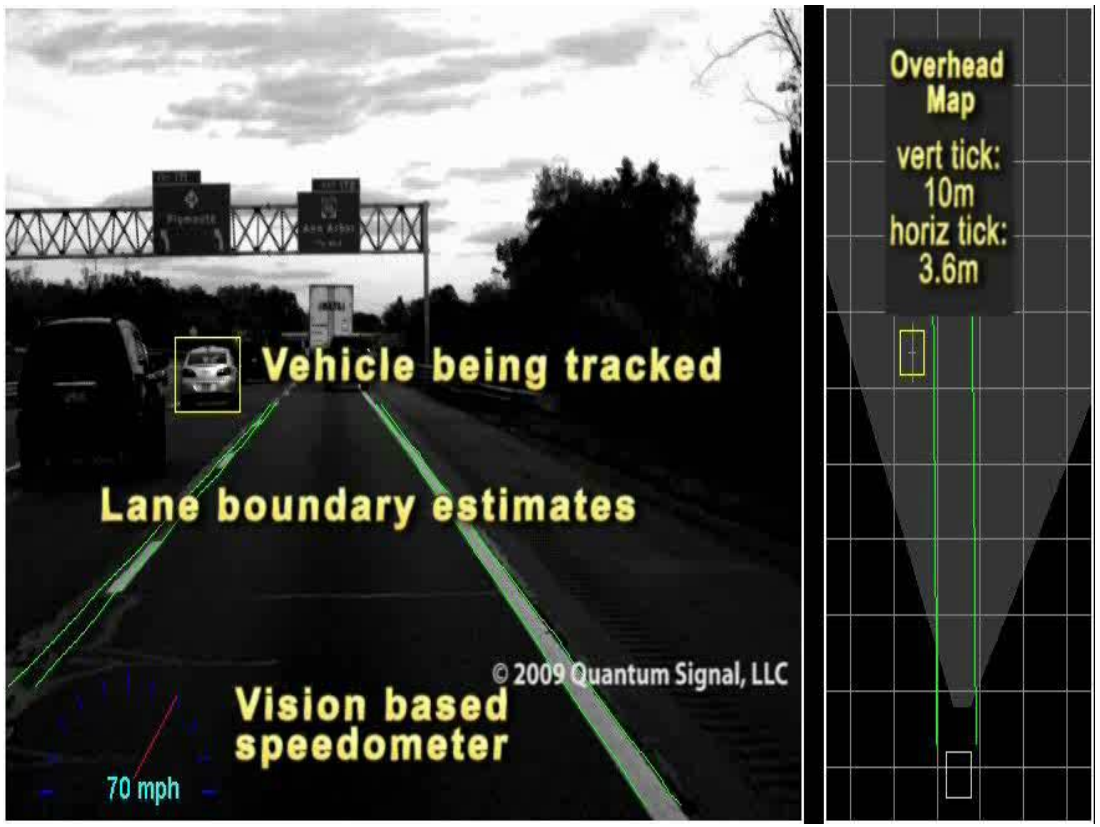
- Typical driverless car “stack” involves some combination of
  - Heuristic rules based on human approaches
  - Algorithms engineered to characterize data, extract specific features, classify
  - Algorithms engineered to adaptively extract, learn features, classify
- “Deep Learning” being applied to overcome difficult algorithmic challenges

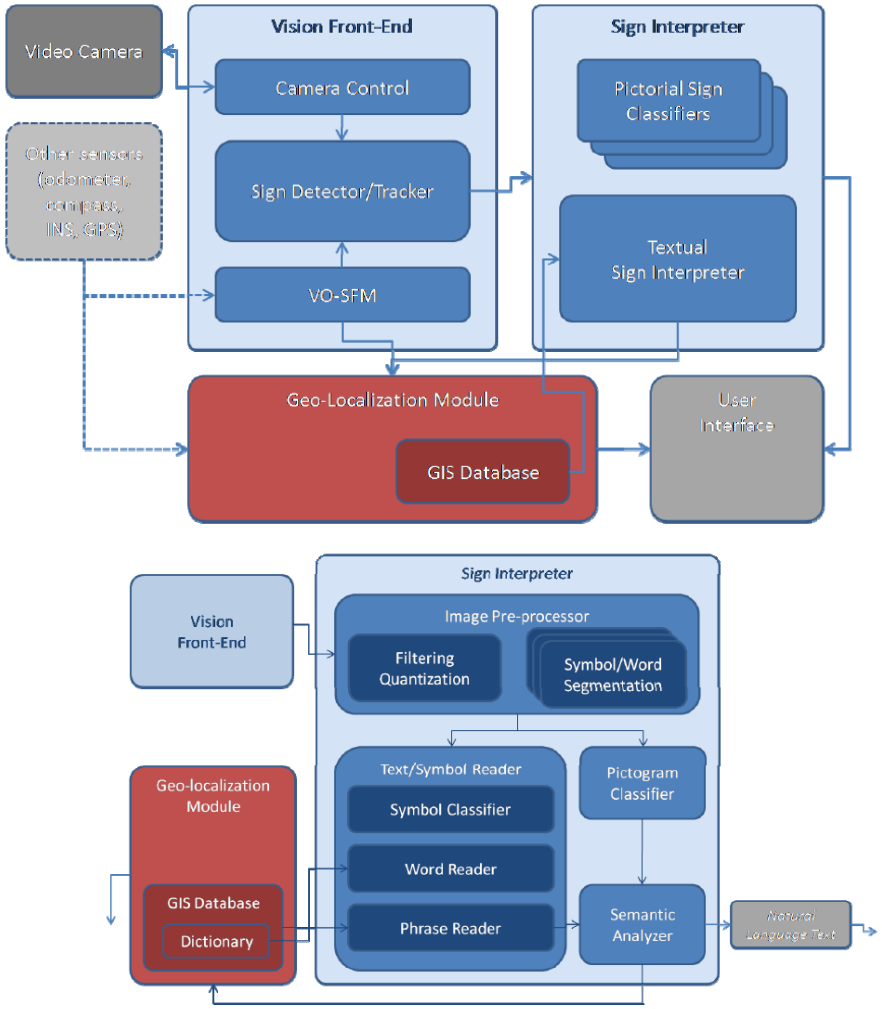


https://www.xenonstack.com/blog/data-science/log-analytics-with-deep-learning-and-machine-learning

- Adaptive techniques require data corpus’ with wide performance-space coverage
  - Some use artificial diversification techniques or M&S environments to assist

Example “Mash Up” Sign Reading ADAS Solution (~2007-2009)

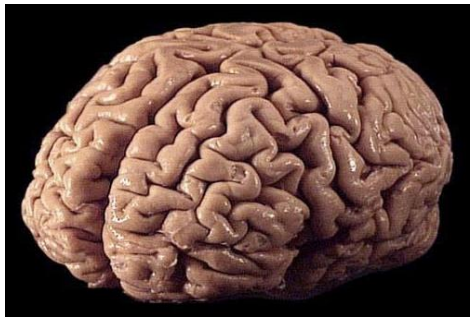


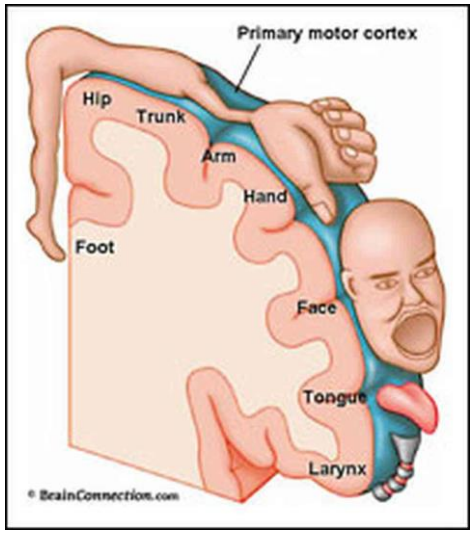


Effective application –
learning plays a role within an overall framework

V. E. Perlin, D. B. Johnson, M. M. Rohde, R. M. Lupa, G. Fiorani, S. Mohammad, "ESARR: enhanced situational awareness via road sign recognition", Proc. SPIE 7692, Unmanned Systems Technology XII, 76920G (8 May 2010); doi: 10.1117/12.850256; http://dx.doi.org/10.1117/12.850256

ANNs are not Brains, Skynet isn't Near





- ANNs, Machine Learning, Deep Learning, etc. have all made strides, are good tools to use for specific types of situations/problems
- "Whitewashing" of limitations based on notions of biomimicry
- ANNs emulate simplified notions of how real neural networks operate
  - They don't "reason"
  - We do not yet truly understand connectivity and functioning of human brains
  - We know some things, though! ☺
- Common (but false) argument: the ability to generate computing hardware at same or better density than human brains means we'll be able to build effectively equivalent electronic brains
- Don't be swayed by those who predict the end-game for this technology as truly independent, human-like thought and decision making
  - Turns crazed tin-hat member of public against it unnecessarily
  - Hurts investments in research (remember who signs the checks)
  - We need more breakthroughs!

Drawbacks to “Learning” Approaches

- Massive datasets required for training, testing
  - Not just video – much of the sensor suite
  - Has to capture normal and abnormal situations – edge cases (see next slide)

- “Black box” algorithms
  - No human-relatable elements
  - “No user serviceable parts inside – return to manufacturer”

- Unpredictable behavior in novel circumstances
  - ANNs and their kin can produce odd results → *not adaptive like real humans!*
  - No matter how much “real data” you train it on, the world is a crazy place
  - Can mitigate with heuristic rule base, but that too can be fraught with challenges

(Spiderman ©Marvel Comics)

- Powerful results can be wielded by newbs, easily deceiving
  - Natural appeal to pumping in data, telling it what you want, getting out results!
  - Need to understand methods deeply → effectively leverage in products!

    Case in point: poor fuzzy-logic based breadmakers

Driving Involves Unpredictable “Edge Cases”

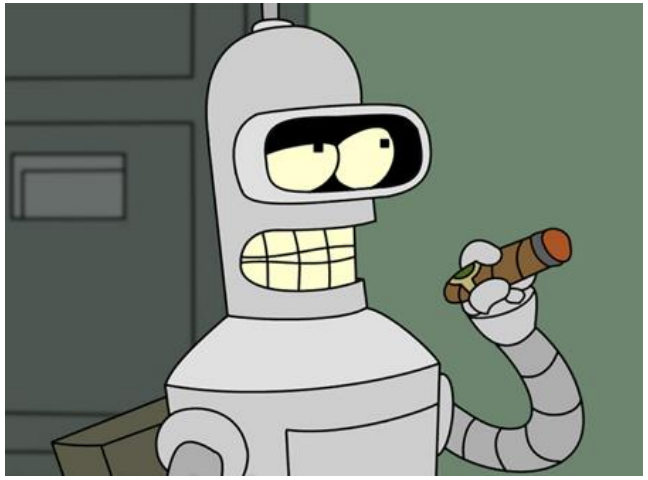
- Many unpredictable cases
- Algorithm development very difficult
  - Adaptive tech to address?
- How do ANNs react to completely unexpected inputs?

(special thanks to “TwisterNederland” for the video!)

Mitch's Paradox

Who do you trust to drive your kid's bus?

Algorithm



- Doesn't get tired
- Repeatable performance
- Man made, tested over last 5-10 years
- Doesn't feel consequences, no self preservation

Human

- Gets tired, has good days and bad
- Higher variance in performance
- CPU/sensing evolved over millions of years
- Feels consequences, self preservation motivation

Remember, edge cases are critical!

How deterministic is your system? Provable?

(Bender and Otto belong to Matt Groening, Fox, etc..)

All of that being said….

- There are substantial strides being made based on a combination of
  - Algorithm development and advances
  - Sensor development and advances
  - Cheap and ubiquitous computing power

- Few would have predicted the rate of advancement, investment, and potential acceptance
  - “We don’t foresee a lot of cameras in cars” – Major Tier 1, 2010

- ANNs, Machine/Deep Learning, and related technologies are clearly playing a role

My Recommendations

- Choose the right algorithmic weapon(s) to slay any given dragon(s)
  - Don’t believe the hype - no one algorithm or technique will be the magic silver bullet
  - Beware powerful weapons in the hands of newbs
  - “Deep Learning” etc. are just another tool in the toolbox – right place, right time
- Hire the best folks you can
  - “Smart and get things done”
  - Solid math background key to robust algorithms
  - Solid software background key to robust implementations
- Use Modeling and Simulation
  - Truly exercise the algorithms and software in a statistically meaningful manner
  - Explore “edge cases” in deeper ways
- Think deeply about direct and indirect consequences of your algorithms
  - Cars and shuttles aren’t breadmakers
  - Contemplate the school bus

Questions? Comments?

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