A machine learning approach to modeling the magnetosphere

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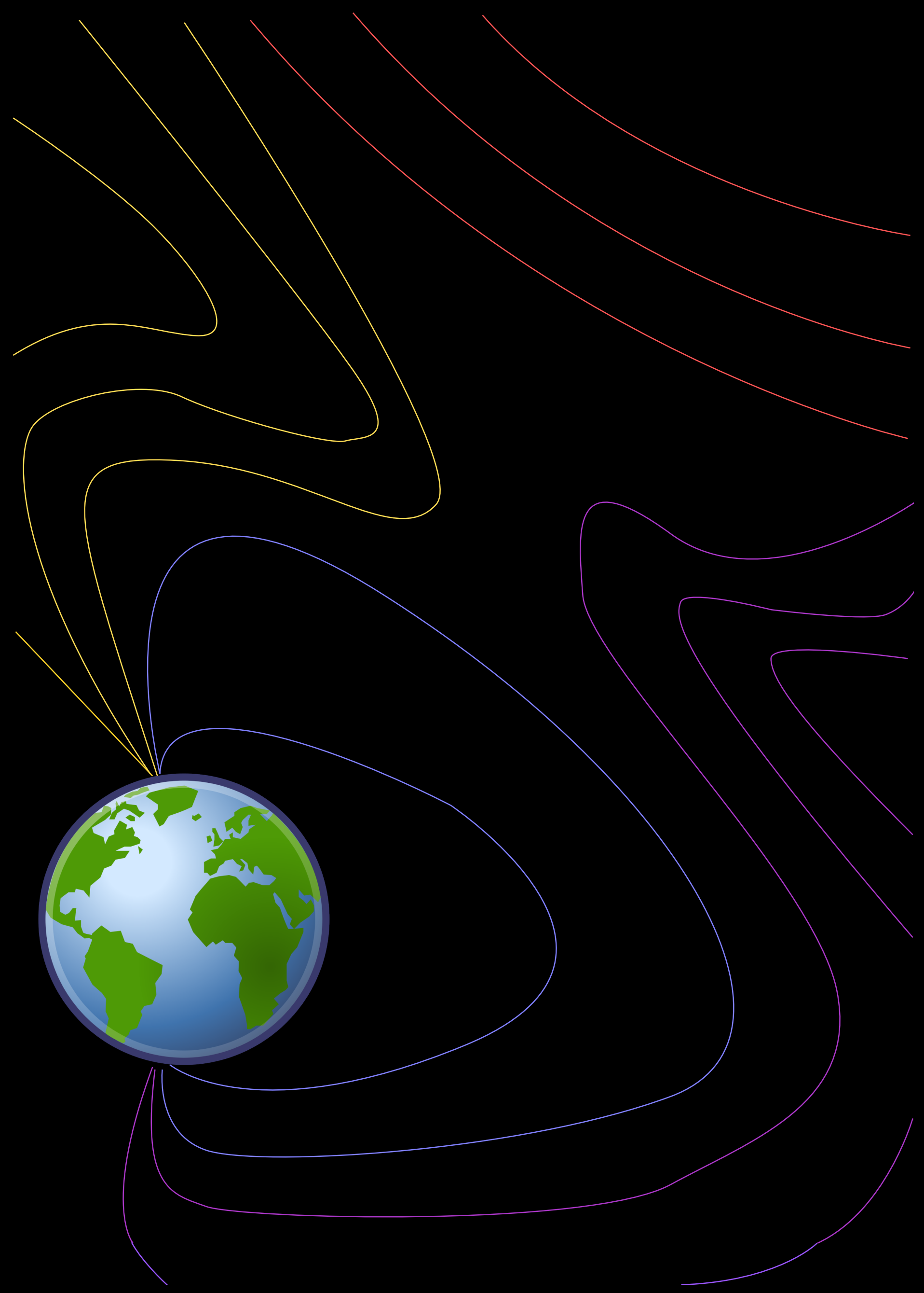
Magnetosphere

- Magnetic reconnection drives space weather
- Magnetic field lines can be classed into ‘open north’, ‘open south’, ‘solar wind’, and ‘closed’
- We want to get a clear picture of these magnetosphere topologies for space weather forecasting operations

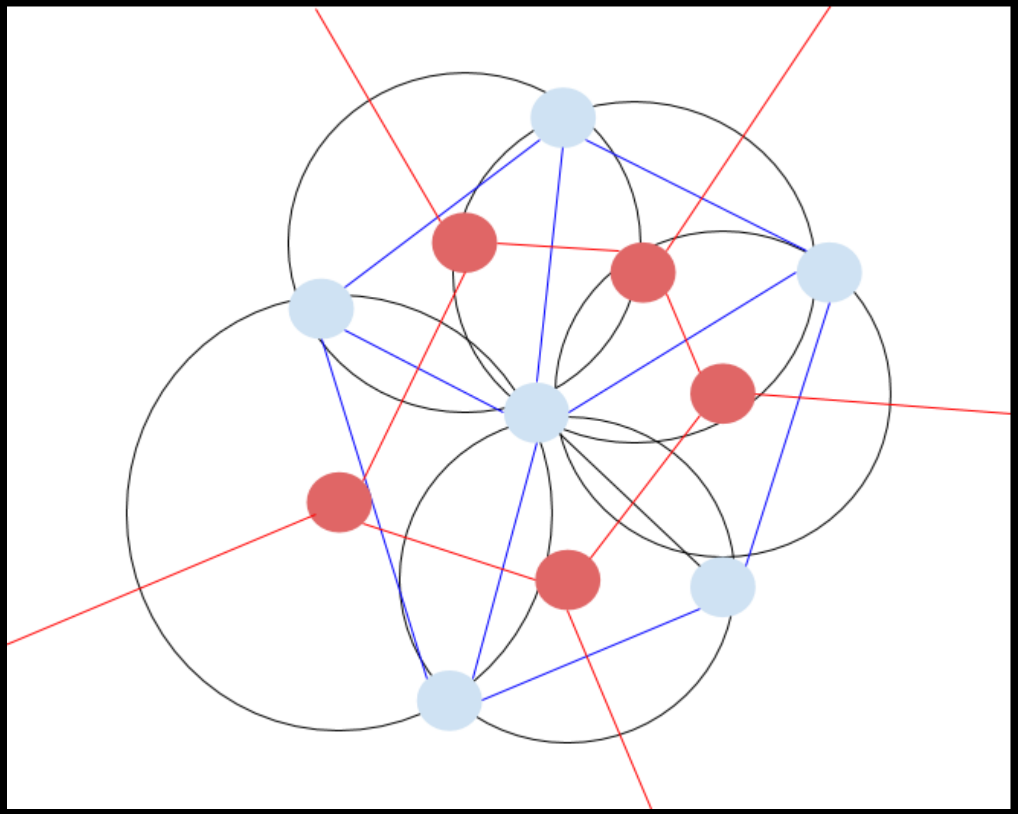


Challenges

- Computationally expensive: relies on runge-kutta tracing over 3D space
- Imprecise: results in separator surfaces bound by local resolution

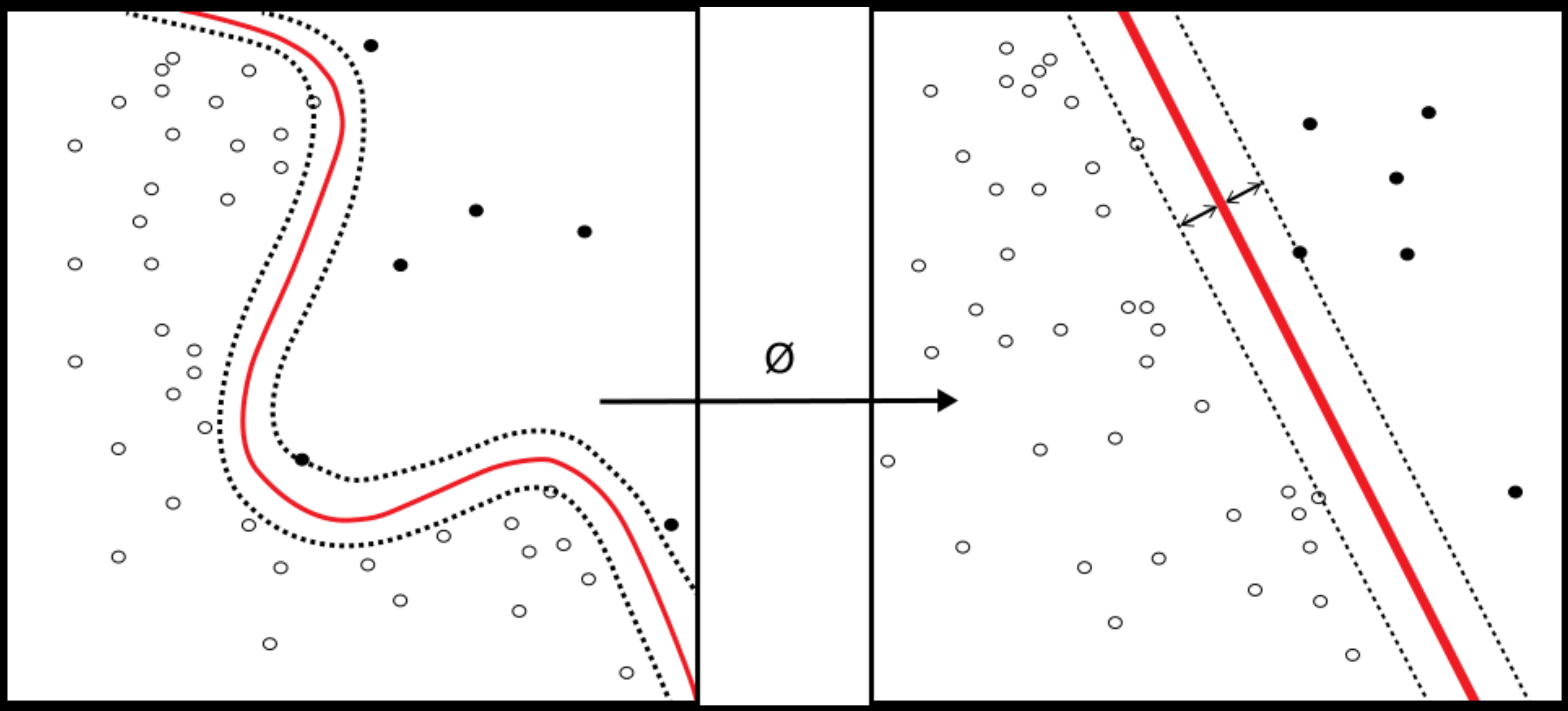
Furthest Point Seeding

- Place seed points in delaunay triangulation
- Take center with largest circumradius
- Trace from center



- Insert field line points into Delaunay triangulation
- Repeat!

Support Vector Machines



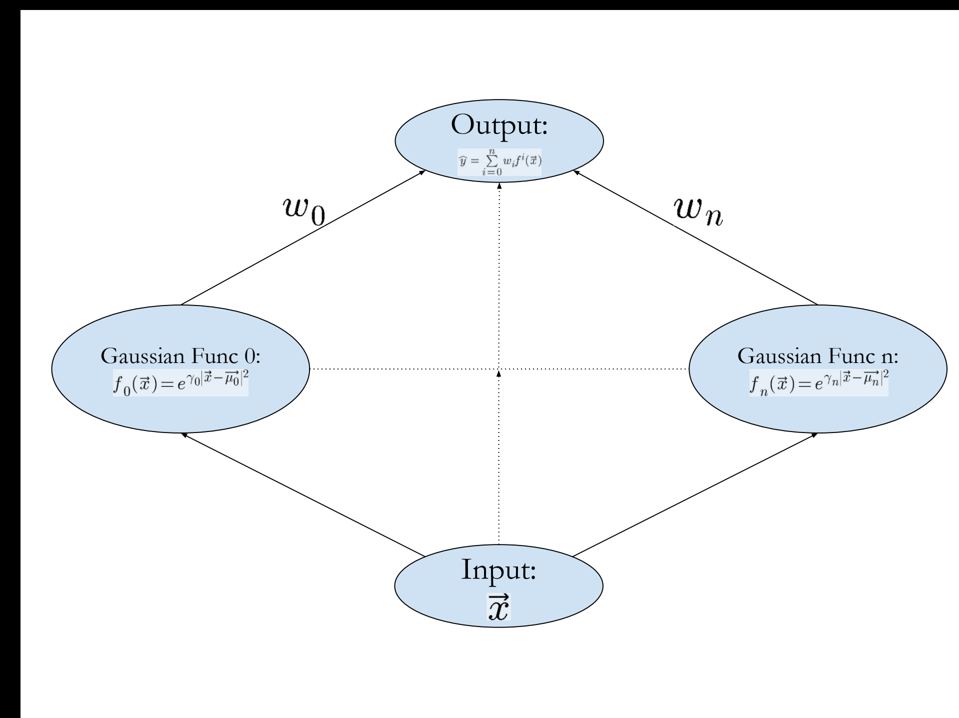
- Find function of the form $f(\vec{x}) = \sum_{i=1}^{N} \alpha_i \langle \vec{x}_i \vec{x} \rangle$ which maximizes $\max \sum_{i}^{m} \alpha_i - \frac{1}{2} \sum_{i=1}^{m} \sum_{j=1}^{m} \alpha_i \alpha_j y_i y_j \langle x_i, x_j \rangle$

Radial basis functions

- Models a scalar quantity as a linear composition of radial basis ‘kernel’ functions

- Models parameters with a ‘principle of locality’

- Minimize error

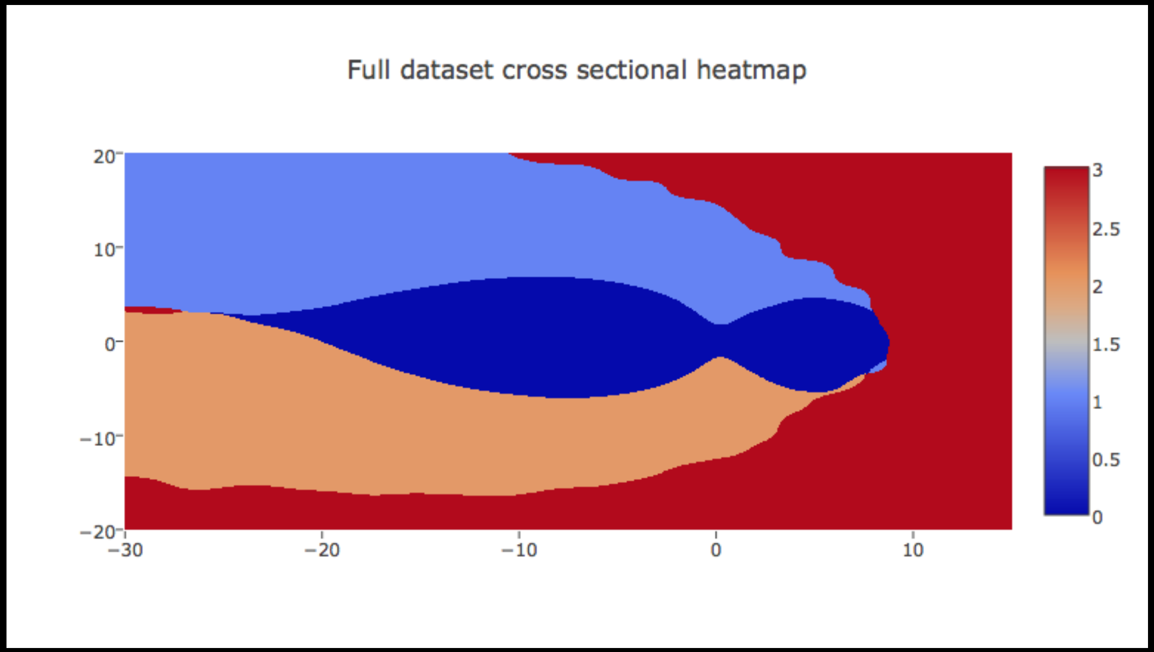


$$E(\hat{y}) = (\hat{y} - y)^2$$

$$\nabla E = \sum_i \frac{\partial E}{\partial w_i}\hat{w}_i + \frac{\partial E}{\partial \gamma_i}\hat{\gamma}_i$$

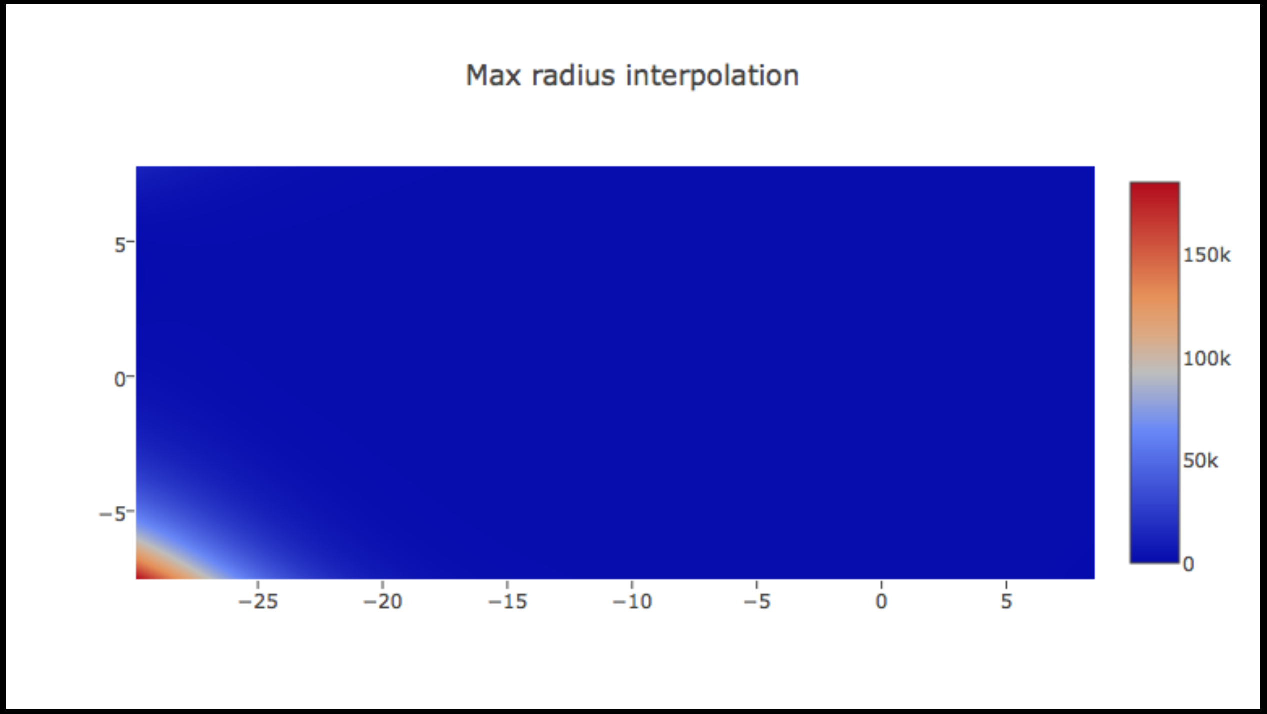
$$\frac{\partial E}{\partial \gamma_i} = \frac{\partial E}{\partial \hat{y}}\frac{\partial \hat{y}}{\partial f}\frac{\partial f}{\partial \gamma_i}$$

SVM Results



- Visualization divides space into topological regions
- 98% prediction accuracy (p = 3.4 E-15)
- 475 sec training; 743 sec for 1000000 queries

RBF Results



- Accuracy wanting, but gives qualitative picture
- Mean squared error = 5 (30% error)
- Training time 81 secs; 4.2 secs 30000 queries

Conclusions

- Machine learning approach is fast
- Paints a good qualitative picture for visualization
- Needs additional optimizations—GPU parallelism
- Will be integrated into Kameleon Live: *everyone gets* access to space weather analysis tools