Formalizing Interruptible Algorithms for Human over-the-loop Analytics

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Key Problems

Learning algorithms are completely autonomous.

Predictive models are hard to digest.

Humans are slow thinkers.
\[(x-2)^2(y-2x+2)^2(y+2x-10)^2(x-4)^2(y-2x+8)^2(y+2x-16)^2\left(y-3-3\left[x-\frac{11}{2}\right]^2\right)^2(x-8)^2\]
\[\cdot \left(y-2-3\left[x-\frac{8}{2}\right]^2\right)^2(x-11)^2\left(y-\frac{1}{2}x+\frac{5}{2}-3\left[x-\frac{11}{2}\right]^2\right)^2\left(y+\frac{1}{2}x-\frac{17}{2}-3\left[x-\frac{11}{2}\right]^2\right)^2(x-15)^2\]
\[\cdot \left(y-4-3\left[x-\frac{14}{2}\right]^2\right)^2(y-2x+52)^2(x-17)^2(y+x-21)^2(x-19)^2(y-x+17-3|x-20|^2)^2\]
\[\cdot (y+x-23-3|x-20|^2)^2(y-x+19-3|x-21|^2)^2(y-3-3|x-21|^2)^2(x-25)^2(y+\frac{1}{4}x-\frac{41}{4}-3\left[x-\frac{25}{4}\right]^2)^2\]
\[\cdot \left(y-\frac{1}{8}x-\frac{1}{8}-3\left[x-\frac{25}{2}\right]^2\right)^2\left(y+\frac{5}{8}x-\frac{151}{8}-3\left[x-\frac{25}{2}\right]^2\right)^2\left(y-2x+54\right)^2(y+2x-62)^2\left(y-3-3\left[x-\frac{57}{2}\right]^2\right)^2\]
\[\cdot (x-31)^2(y+x-35)^2(x-33)^2(x-34)^2\left(y+\frac{1}{2}x-21-3\left[x-\frac{34}{2}\right]^2\right)^2\left(y-\frac{1}{2}x+15-3\left[x-\frac{34}{2}\right]^2\right)^2\]
\[\cdot ((x-38)^2+(y-3)^2-1)^2(x-40)^2(y+2x-84)^2(y-2x+80)^2(x-42)^2(x-43)^2\left(y-2-3\left[x-\frac{43}{2}\right]^2\right)^2\]
\[\cdot (y-3-|x-47|)^2((x-47)^2+(y-3+\sqrt{y^2-6y+9})^2)^2+(y^2-6y+8+\sqrt{y^4-12y^3+52y^2-96y+64})^2=0\]
Data -> Learning -> Model

Can I help?
Anytime Algorithms

Initialization → Acceptable Answer → ... → User terminates at any point

Interactive Algorithms

Initialization → Interaction → Termination

Computation → Computation

Stop and Wait

(Graham et al., 2017)
Interruptible Algorithms

Initialization -> Computation -> Termination

Interaction

Optional Interactions
How can I help?

Repose the question → Change model attributes

Give more information → Add/Remove data
Key phrase: might as well start over
Minimally Increase Execution Time for Better Results

$$I_{A,U} > \frac{O(A)}{O(C)}$$

Greater than 1: Okay to interrupt

Less than 1: Just start over

(Graham et al., 2017)
Key Questions

What kind of changes can be made to positively affect outcomes?

How do I know I’ve made things worse?
Visualization

Is there a model agnostic way to visualize learning?

Will the visualizations be readable to non-experts?

In what contexts will humans have enough time to react?
Questions?
Motivations - Data Mining and Machine Learning

- **Long running**
  - Days, Weeks
  - Changes in parameters must be made *a posteriori*

- **Static**
  - Changing data means re-training model

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13 (Graham et al., 2017)
Humans Getting Involved

- Interactive
  - Humans *IN*-the-loop
  - Focus on model accuracy
- Anytime
  - Humans *ENDING*-the-loop
  - Focus on model availability
- Interruptible
  - Humans *OVER*-the-loop
  - Manage the accuracy/availability tradeoff

Availability vs. Accuracy Tradeoff

14 (Graham et al., 2017)
Interactive Algorithms

- Learning models asking humans questions
  - Stop-and-wait conditions
- Improves accuracy with detrimental increases to runtime
Example Interactive Approaches

- **Awasthi et al.**
  - Hierarchical clustering
  - Analyst can split/merge clusters at every level

- **Lad and Parikh**
  - Image clustering
  - Algorithm asks the analyst for the answer

- **Amershi et al.**
  - Clustering in social networks
  - Improvement happens on user choice
Anytime Algorithms

- Learning models build to an acceptable point, then improve until user says to stop or convergence
  - Assumes models improve with longer runtimes
- Allows analysts to train their comfort level

Initialization → Acceptable Answer → ...

User terminates at any point

17 (Graham et al., 2017)
Anytime Approaches

- Ueno et al.
  - Stream mining
  - Anytime structure accounts for fluctuations in data streams

- Vlachos et al.
  - Time Series clustering
  - Coarse clustering for a rough estimate, then iteratively improve.
Meet in the Middle - Interruptible Algorithms

- Learning algorithms follow predefined behavior allowing analyst to make changes at available times
  - Analyst can intervene only if they find it necessary
- Increases in execution time depend on user involvement

![Diagram showing the lifecycle of an algorithm with stages: Initialization, Computation, Interaction, and Termination, with optional interactions marked.]

19 (Graham et al., 2017)
The Interruptibility Index

- Measures change affects relative to the algorithm
  \[ I_{A,U} > O(A)/O(C) \]

- “Algorithm A is interruptible in attribute \( U \) if the ratio of the complexity of A to the complexity of a change \( C \) in \( U \) is \( > 1 \)”
  \[ I_{A,U} > I_{A,S} \]

- “If the interruptible index in attribute \( U \) for algorithm A is greater than the interruptibility index in attribute \( S \), then the change in \( U \) is less interruptible than the change in \( S \)”

20 (Graham et al., 2017)
HOLA - An Interruptible Algorithm Provider

- **(H)uman (O)ver the (L)oop (A)nalytics**
- **Architecture**
  - User Space
    - Interact with an analyst
    - Visualization system conveying model state
    - Convert user gestures and actions to machine readable ‘system calls’
  - Kernel Space
    - Manage concurrent changes in data and model information
    - Store and manage raw data set
    - Return renderable model state to User Space
System Calls

- Atomic operations that make up interrupts
- Data Changes
  - Update a record
  - Remove a record
  - Add a record
- Data Model Changes
  - Update hyper parameter
  - Inspect model state
- Control Changes
  - Open connection
  - Close connection
Architecture

Kernel Space
- Algorithm Implementation
- Data Storage

User Space
- Interrupt Interpreter
- User Visualization

Data

System Calls

Interrupt

Rendered State

23 (Graham et al., 2017)
Interruptibility Example: KMeans Clustering

- **KMeans Algorithm:**
  - Initialize k clusters
  - Randomly assign points to each cluster
  - Calculate initial cluster centers
  - While a change has been made
    - Calculate closes cluster center to each point
    - Reassign the point to closest cluster

- **Decisions to be made**
  - What changes are interruptible?
  - Where should the interrupts happen?
KMeans Interruptibility Indices

- Complexity of KMeans = $O(nkI\theta)$
- Complexity of changing a single data point $q$ used by KMeans = $O(\theta)$
- $I_{KMeans, q} = O(nkI\theta) / O(\theta) = nkI$
  - $n, k, I$ are constants with respect to a data point
  - Interrupt is constant time
- Complexity of changing k hyper parameter in KMeans = $O(\theta)$
- $I_{KMeans, q} = O(nkI\theta) / O(\theta) = nkI$
  - $n, I$ are constants with respect to k hyper parameter
  - Interrupt is linear time
Where to Interrupt

Listing 1  Sample KMeans Interruptible Implementation

```python
@hola(data_points, K)
def find_centers(data_points, K):
    oldmu = random.sample(X, K)
    mu = random.sample(X, K)
    while not has_converged(mu, oldmu):
        oldmu = mu
        hola.interrupt()
        clusters = cluster_points(X, mu)
        mu = reeval_centers(oldmu, clusters)
    return (mu, clusters)
```
Summary

- Data mining and machine learning processes take significant amounts of time and are not adaptive to changing contexts.
- Interactive and Anytime algorithms put the human in the loop to improve accuracy and time with significant tradeoffs.
- Interruptible algorithms are designed to give the user the *option* to interact with an algorithm with no penalties if he or she chooses not to do so.
- HOLA is a system designed to make use of an operating system architecture to manage the interrupts and visualization.
Future Work

- What would a visualization system that adapts to various model and data states look like?
  - Buffering state for concurrent modification
- Incorporate git-like strategies for data experimentation
  - Branching data to allow for concurrent experiments that are independent
  - Merges and commits to persist successful changes’
- User studies
  - Analyst may not have prior knowledge of their data
  - Ensure visualization can communicate data and model state
References

References cont.