KeepDelta: A Python Library for Human-Readable Data Differencing

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Summary

Efficiently managing evolving data is crucial in applications like computational simulations and sensing, where dynamic data tracking and processing are essential. In simulations, the traditional method known as full-state encoding stores the entire system state, including all nested data structures and variable values, at every timestep. While simple to implement, this approach is highly storage intensive. On the other hand, recalculating states from scratch to avoid storage demands is computationally expensive. Similarly, in sensing, continuously transmitting full data snapshots is inefficient, leading to increased bandwidth consumption and latency. *KeepDelta* addresses this challenge by providing a lightweight Python library that captures and applies only the changes (deltas) between successive states of complex, nested Python data structures. Designed for clarity and ease of use, KeepDelta produces human-readable outputs, facilitating debugging and analysis in research applications.

Figure 1: KeepDelta logo

Statement of need

High-frequency data sampling is fundamental in both scientific simulations and real-world sensing applications, where large volumes of evolving data must be efficiently managed. Both domains, whether generating synthetic data through computational models or collecting real-time measurements from physical sensors, face a common challenge: storing, transmitting, and processing dynamic data without excessive redundancy.

First and foremost, KeepDelta applies to simulation. Simulation is a widely used methodology across all applied science disciplines, offering a flexible, powerful, and intuitive tool for designing processes or systems and maximizing their efficiency (Kleijnen, 2018). Specifically, computational simulations are invaluable tools for studying complex systems and their behaviors (Aumann, 2007). These studies often take the form of computer experiments, where data is generated through pseudo-random sampling from known probability distributions. This approach serves as an invaluable resource for research, particularly in evaluating new methods and comparing alternative approaches (Morris et al., 2019).

Secondly, KeepDelta also applies to sensing. Sensing technologies are employed across diverse scientific and engineering domains, enabling continuous monitoring and analysis of dynamic environments. It is common for these systems to utilize a set of sensors to capture real-time

34 data, which is essential for studying systems behaviors, informed decision-making, and system
35 optimization (Al-Qurabat et al., 2021; Felton et al., 2018).

36 Both simulations and sensing require mechanisms to track and store evolving states of data
37 structures over time. In simulations, the naive approach of saving full snapshots at every
38 timestep leads to excessive storage demands, while recalculating states from scratch is compu-
39 tationally expensive. Similarly, in sensing applications, continuously storing or transmitting
40 full data snapshots is impractical, particularly in bandwidth-limited and remote environments.
41 Instead of relying on these easy-to-implement but inefficient methods, KeepDelta introduces
42 an optimized middle ground by saving only the *deltas* (changes) between states, significantly
43 reducing storage and computation overhead. This Delta Encoding technique has been success-
44 fully applied in other domains where managing evolving data efficiently is critical, such as web
45 development (Hoff et al., 2002) and software version management (Percival, 2003).

46 Human-readability is crucial for debugging and development in both simulation and sensing
47 projects, and KeepDelta is tailored specifically for this purpose. It is lightweight and has no
48 dependencies, supports native Python data structures, and generates results that are easy to
49 interpret. This makes it an ideal tool for Python developers and researchers seeking a simple
50 yet powerful solution for change management. By providing clear, human-readable output,
51 KeepDelta enhances both the development process and debugging efficiency, making it easier
52 to track and manage changes in complex projects involving both computational models and
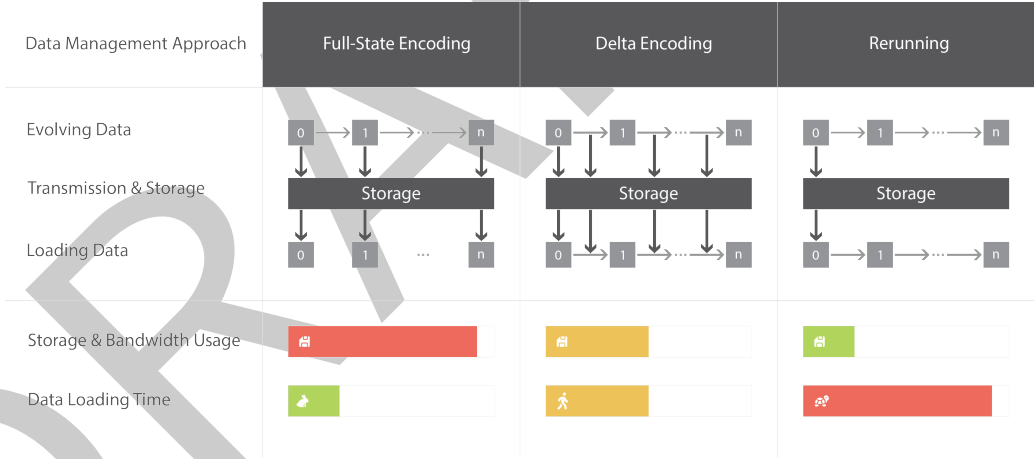53 real-world sensing systems.

Figure 2: Comparison of data management approaches in evolving systems. Full-state encoding incurs high storage and bandwidth costs, while delta encoding saves only changes for efficiency. Rerunning reduces storage but increases computation and is often impractical for sensing real-world data. The bottom gradients illustrate trade-offs: storage/bandwidth decrease left to right, while data loading time increases.

Comparison to Existing Tools

55 In the landscape of Python libraries designed for delta encoding, several notable tools have
56 emerged, each with distinct features and applications. xdelta3 (Colvin, 2017) and its pre-
57 decessor, xdelta (MacDonald, 2016), are tools that perform delta encoding at the binary
58 level. These utilities are particularly effective for binary file differencing and are widely used in
59 version control systems and data synchronization tasks. However, both are considered outdated
60 and are no longer actively maintained. Their operation at the binary level results in outputs
61 that are not human-readable, and they are not tailored for Python data structures, limiting
62 their applicability in Python-centric workflows. deepdiff (Dehpour, 2025) is a contemporary
63 library that facilitates the identification of differences between complex Python data structures,

including dictionaries, lists, and sets. It extends support to external libraries like `NumPy` (Harris et al., 2020), enhancing its versatility. However, this integration can lead to outputs that are less human-readable compared to `KeepDelta`. Additionally, deepdiff introduces weighty dependencies that may not be necessary for all projects. In contrast to these alternatives, `KeepDelta` is a lightweight Python library tailored for simulations and sensing, focusing on efficient delta management for built-in Python data structures. It produces human-readable outputs that facilitate debugging and research workflows. Written entirely in Python and free of external dependencies, `KeepDelta` integrates seamlessly into Python-centric workflows, including simulation, sensing, and data analysis pipelines.

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