A Brief History of Liquid Software

Cesare Pautasso

http://www.pautasso.org/
@pautasso@scholar.social

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Abstract

The concept of liquid software, i.e., software with flexible deployment, over the past two decades has appeared in the fields of edge computing, Internet of Things (IoT), Human-Computer Interaction, DevOps and Web engineering. In this paper, we survey, compare, and provide a comprehensive definition of liquid software by analyzing how the metaphor has been used in existing literature and identifying gaps and inconsistencies in the current vs. past understanding of the concept. Overall, liquid software can be seamlessly deployed and redeployed within a dynamic and distributed runtime environment in response to changes applied to the set of available devices and to the software itself. Liquid software has been introduced in the context of active networks and intelligent environments, it has been applied to describe the user interaction with multi and cross-device user interfaces, it has found a promising foundation in Web technology, continuous software delivery pipelines, as well as isomorphic software architectures running across the IoT, edge and Cloud continuum.
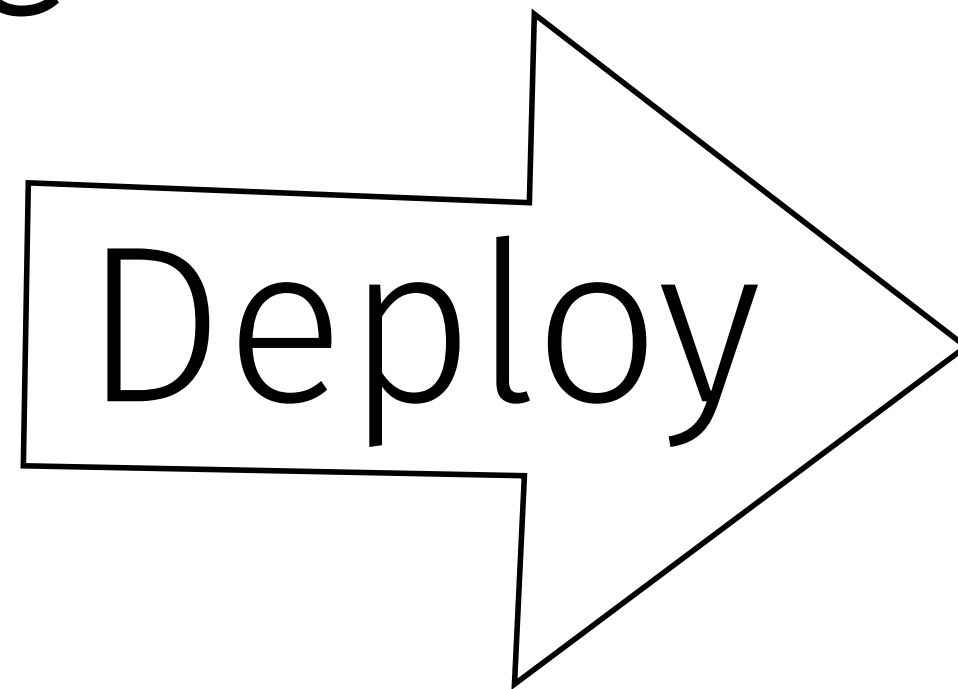
Flow

Source

Sink

Adapt
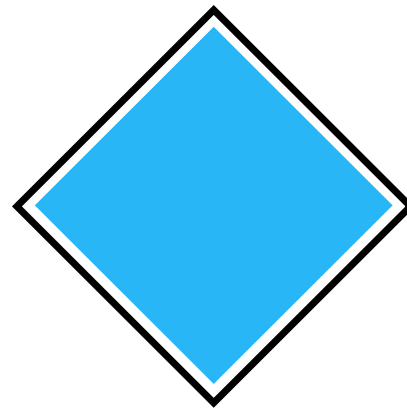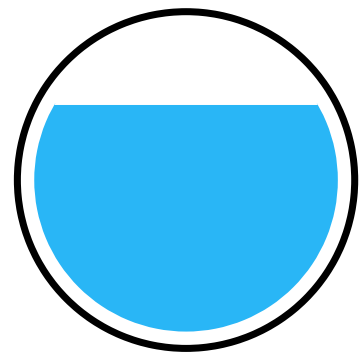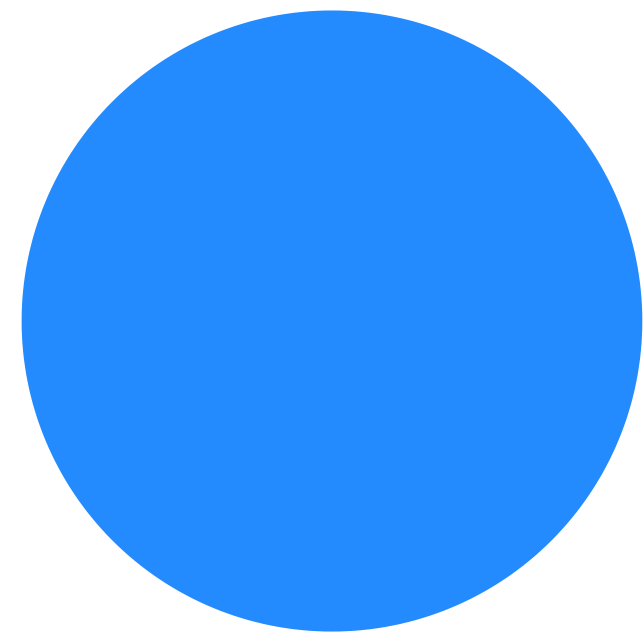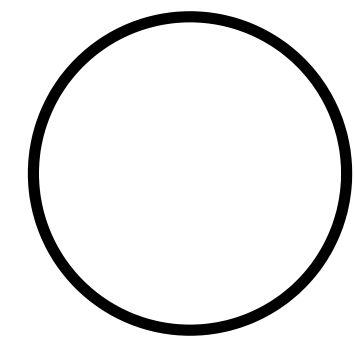
Responsive

Liquid

Liquidity

Flexibility

Deployability

Liquid = Flexible Deployment

Software

Devices

Deploy

A brief history of Liquid Software

| 1996 | 1997 | 1998 | 1999 | **2000** | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | **2010** | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | **2020** | 2021 | 2022 | 2023 |

- Media (2003)
- Metal (2008)
- Computing (2014)
- Software (Continuous Updates) (2018)
- Fluid Computing (2005)
- Model (2016)
- Mode (2020)
- User Experience (2014)
- Software (Active Networks) (1996)
- Software Manifesto (2014)
- Handover (2020)
- AI (2023)
- Context (2016)
- State Machine (2002)
- Web Apps (2015)
- Functions (2022)
- Load Balancing (1996)
- Fluid Architecture (2006)
- Web Component (2016)
- Media Queries (2020)
- Web Services (2011)
- Stream Processing (2015)
- Web Workers (2019)

Liquid Software

Active Networks

Low-level, communication-oriented code that easily flows from machine to machine

Liquid Load Balancing

Load Balancing

Shifts in workload allocation are seen as liquid flow reaching a stable equilibrium in a hydrodynamic system

Liquid State Machine

Theoretical Computer Science

A generalization of a finite state machine to continuous time and continuous ('liquid') internal states

Liquid Media

Ubiquitous Computing

Seamless handover of streaming media

Fluid Computing

State Replication

The seamless transfer of an application's data and state between devices, possibly without user intervention.

Fluid Architecture

Intelligent Environments

Accommodate continuous user-induced structural changes without adversely affecting the system's behavior

Liquid Metal

Programming Languages

Programming with a single high-level OO language that maps well to both CPUs and FPGAs.

Liquid Web Services

Service-Oriented Computing

Provide elastic scalability to applications deployed on heterogeneous environments

Liquid Software Manifesto

Multi-device User Interfaces

A multi-device user experience where software can seamlessly and effortlessly flow from one device to another

Liquid Computing

Multi-device User Interfaces

Your activities, not just your data, flow from device to device

Liquid Stream Processing

Stream Processing Pipelines

Autonomously deal with deployment, parallelization, migration, and recovery of streaming operators

Liquid Privacy Spheres

Privacy

Unclear boundaries, confusing settings make users unaware of personal information leaks

Liquid Web Applications

Multi-device User Interfaces

Benefit from all user-owned devices' computing, storage, and communication resources, while smoothly roaming across Web browsers following the user attention and usage context.

Liquid Web Component

Web Technology

Web Component whose HTML/CSS/JS assets and dynamic state can be dynamically redeployed across different Web browsers

Liquid Context

Context-Awareness

Seamless synchronization of contextual metadata for consistently personalized multi-device applications

Liquid Model

Model-driven Engineering

Model evolution reflecting runtime operations (Digital Twin)

Liquid Software Updates

DevOps Pipelines

Practices to enable continuous updates and evolution of software systems without downtime or disruption to end users

Liquid Web Worker

Opportunistic Computing

Transparent offloading of Web workers to run on nearby devices

Liquid Media Query

Multi-device User Interface

Detect which devices, roles, users are present to declaratively control the placement of liquid Web components across a distributed user interface

Liquid Handover

6G Networks

Seamless handover of tasks being shared between devices and edge nodes while devices move in the network.

Liquid Mode

Responsive User Interfaces

A breakthrough reading experience that enables a much easier way to read PDF documents on mobile

Liquid Functions

Serverless Computing

Code offloading and placement depending on annotations, load metrics, data affinity, and expected capacities
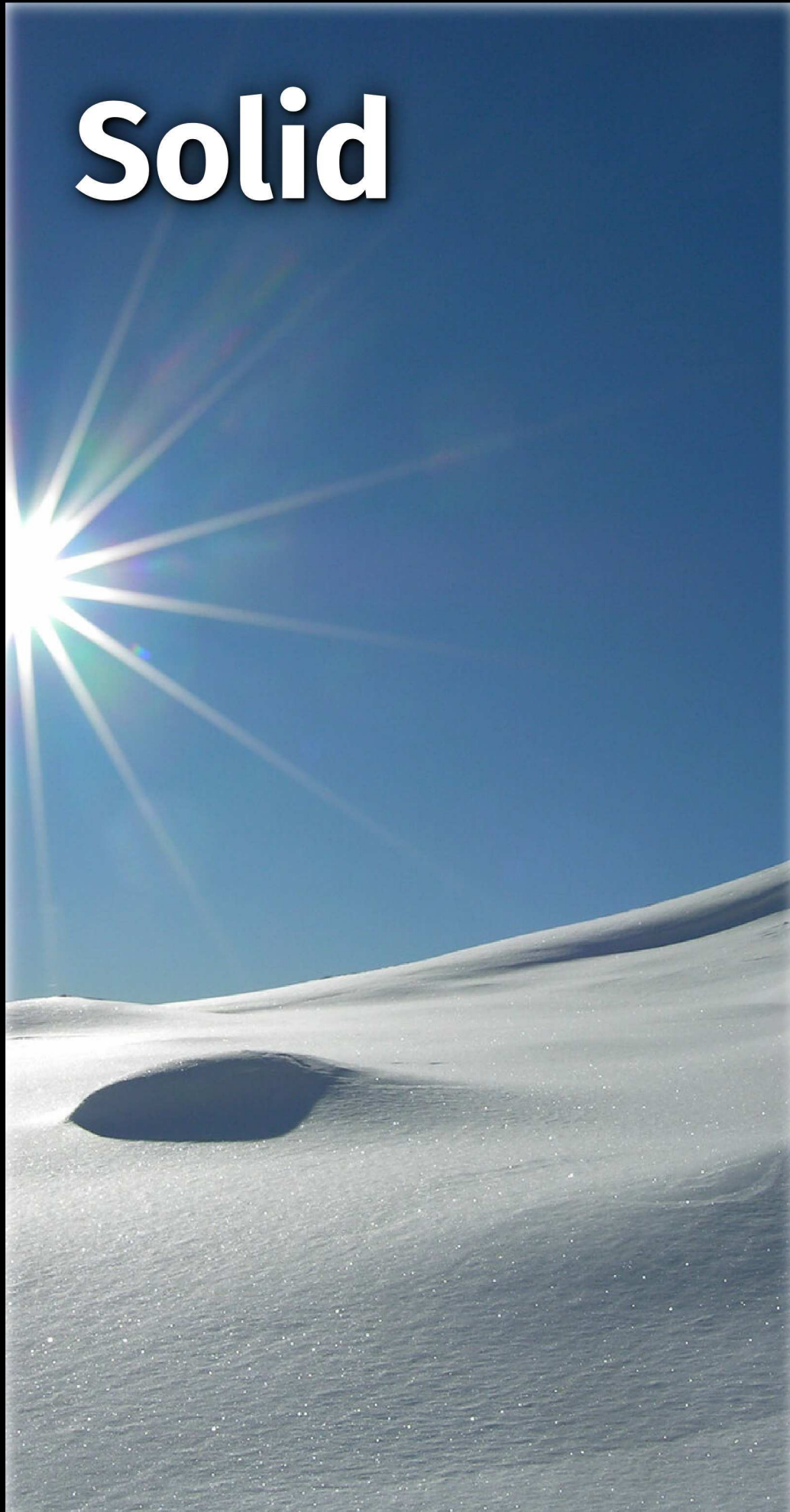
Liquid AI

Machine Learning

Flexible deployment of continuously re-trained models along IoT-Edge-Cloud analysis pipelines

"States" of Software

Solid

Liquid

Cloud

My Software

My Device

My Data

My Software

My Devices

My Data

Your Software
Their Devices
"My" Data

Liquidity

Flexibility
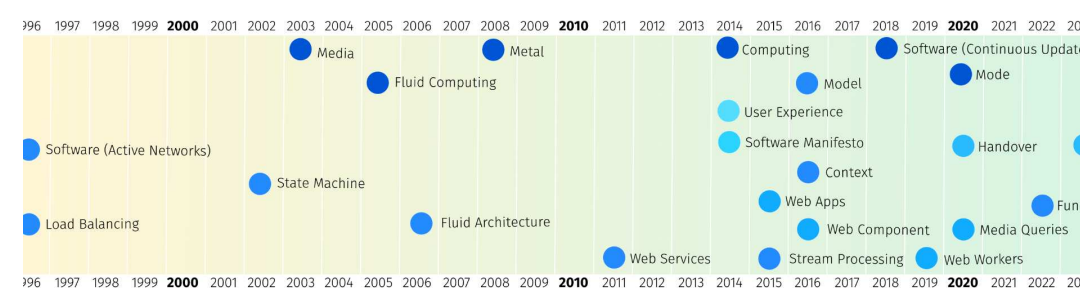
Deployability

Privacy

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Cesare Pautasso

Liquid = **Flexible Deployment**

Software → Deploy → Devices
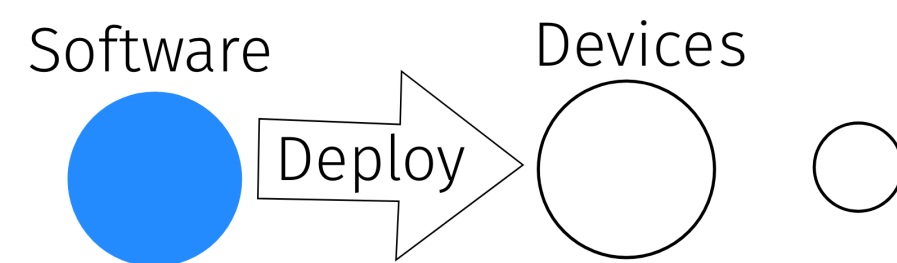
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"States" of Software

Solid | Liquid | Cloud

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http://www.pautasso.org/

c.pautasso@ieee.org

References

- Cesare Pautasso, **A Brief History of Liquid Software**, Proc. IEEE Symposium on Intelligent Edge Computing and Communications (iEdge), Chicago, IL, July 2023