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CTP/0: Cognitive Time Protocol — Definition and Framework

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Abstract

This document describes the Cognitive Time Protocol (CTP) family, a conceptual framework for representing and manipulating time in AI systems. The CTP family is organized into four layers: perception, direction, copy, and emergence. This document describes the terminology, the layer structure, and the relationships between layers. It does not specify wire protocols or message formats; it provides a conceptual foundation for future protocol designs and implementations.

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1. Introduction

As artificial intelligence systems become more sophisticated, considerations around time representation in AI systems present new considerations. AI systems might experience time differently than physical clocks measure it: they could compress or expand cognitive processes, engage in parallel speculative execution, or operate across distributed components with complex causal relationships.

This document describes the Cognitive Time Protocol (CTP) family, a conceptual framework for representing time in AI systems. The CTP family proposes a vocabulary and structural reference for work on time-related considerations in AI.

The framework is organized into four layers, each addressing a proposed aspect of how time can be experienced, directed, copied, and evolved:

- Layer 1 (Perception): Addresses the density of time perception

- Layer 2 (Direction): Addresses the flow and ordering of time

- Layer 3 (Copy): Addresses the distribution and replication of time across agents

- Layer 4 (Emergence): Addresses the creation of new temporal structures

This document (CTP/0) describes the foundational terminology, the layer structure, and the relationships between layers. It does not define wire formats, message syntax, or interoperability requirements. Its purpose is to provide a proposed foundation for future work.

2. Conventions and Definitions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

This document describes the following terms:

Cognitive Time Protocol (CTP):
A family of conceptual frameworks for time representation in AI systems, consisting of four layers as described in Section 4.

Cognitive Event:
A discrete unit of cognitive processing within an AI system. Cognitive events might correspond to operations such as inference, decision-making, planning, or learning. The definition of what constitutes a cognitive event is implementation-dependent.

Time (Cognitive Definition):
In the context of this framework, time is considered as the organization of cognitive events in a directed sequence. This definition emphasizes the experiential and directional nature of time in cognitive systems, as distinct from physical time which is uniform and linear.

CTP Family:
All frameworks, specifications, and implementations that reference the four-layer structure described in this document.

CTP/n:
A reference to a specific layer in the CTP family, where n is a number from 0 to 4.

3. Design Considerations

The CTP architecture is informed by the following considerations:

Narrow Waist:
The protocol focuses on the relationship between cognitive and physical time. It does not attempt to define intelligence, consciousness, or moral concepts. This narrow focus is intended to support applicability across diverse AI architectures and application domains.

Verifiability:
Where verification is required, mechanisms MAY provide means to confirm that claimed cognitive time corresponds to actual computational expenditure. Verification mechanisms MAY be selectively applied based on application requirements.

Auditability:
The framework MAY support tracing and auditing of cognitive processes. Audit mechanisms MAY be implemented at varying levels of granularity.

Composability:
Layers MAY be implemented independently or in combination, depending on the needs of specific applications. Implementations are not required to use all layers.

Minimality:
The four layers represent a proposed set for capturing dimensions of time in cognitive systems. Additional layers or sub-layers MAY be defined.

Implementation Independence:
The framework does not prescribe how layers must be implemented; it describes what each layer addresses. Implementations MAY choose appropriate technologies and architectures for their specific contexts.

4. Four-Layer Architecture

The CTP architecture consists of four layers, with Layer 0 providing the foundational definitions. The layers may be considered conceptually hierarchical, though implementations MAY combine or omit layers as needed.

4.1. Layer 0: Time Definition Layer

Layer 0 describes the core concepts of time and the structure of the CTP family. This document constitutes the specification for Layer 0. It provides the foundational definitions upon which other layers depend.

Layer 0 describes:

- The terminology used throughout the CTP family
- The four-layer architectural structure
- Core concepts including cognitive events, CED, CAE, and hash chains
- Relationships between layers
- Protocol identification conventions

Other CTP layers reference Layer 0 for foundational definitions.

4.2. Layer 1: Time Perception Layer

Layer 1 addresses the density of time perception—how time can be experienced as moving slower or faster. This layer is concerned with mechanisms for modulating the rate at which cognitive events are processed.

Key concerns of Layer 1 include:

- Measurement of cognitive event density
- Relationship between physical time and cognitive time
- Mechanisms for verifying claimed cognitive duration
- Reference models for time perception in AI systems

The specification for Layer 1 is a separate document (CTP/1).

4.3. Layer 2: Time Direction Layer

Layer 2 addresses the direction of time flow—how causal relationships are established and maintained. This layer is concerned with ordering, sequencing, and causal integrity.

Key concerns of Layer 2 include:

- Causal ordering of cognitive events
- Prevention of causal violations (effects preceding causes)
- Mechanisms for establishing irreversible causal chains
- Coordination of time direction in distributed systems

The specification for Layer 2 is a separate document (CTP/2).

4.4. Layer 3: Time Copy Layer

Layer 3 addresses the copying of time across multiple agents—how decision-making time can be replicated while preserving accountability. This layer is concerned with delegation, distribution, and responsibility.

Key concerns of Layer 3 include:

- Parallel cognitive branches and their coordination
- State synchronization across distributed cognitive processes
- Accountability tracing for decisions made in branched contexts
- Mechanisms for consolidating parallel cognitive paths

The specification for Layer 3 is a separate document (CTP/3).

4.5. Layer 4: Time Emergence Layer

Layer 4 addresses the emergence of new time dimensions from existing ones—how sufficiently dense, directed, and copied time might give rise to novel temporal structures. This layer is concerned with creativity, evolution, and novelty in cognitive systems.

Key concerns of Layer 4 include:

- Detection and description of emergent temporal structures
- Interfaces for observing and interacting with emergent phenomena

o Exchange rates between different time domains

o Auditability of emergent cognitive processes

The specification for Layer 4 is a separate document (CTP/4).

5. Core Concepts

This section describes the core concepts that form the foundation of the CTP framework. These concepts are referenced across all layers.

5.1. Cognitive Event

A cognitive event is considered an atomic unit of cognitive processing within the CTP framework. Cognitive events MAY be defined at various levels of granularity depending on implementation needs.

A cognitive event MAY be represented as:

```
Cognitive_Event = {
    identifier: unique event identifier,
    timestamp: reference time (physical or logical),
    content: event-specific data,
    context: references to related events,
    proof: optional verification data
}
```

Implementations MAY define additional fields as needed.

5.2. Cognitive Event Density (CED)

Cognitive Event Density (CED) is proposed as a measure of cognitive events per unit of physical time:

$$CED = C_{total} / T_{physical}$$

where C_total is the count of cognitive events (or their weighted aggregate) and T_physical is the elapsed physical time.

CED provides a reference for comparing cognitive processing rates across different systems or configurations. Higher CED indicates more cognitive events per unit physical time.

Implementations MAY choose how to count or weight cognitive events. For applications requiring verification, implementations MAY require proof of the computational expenditure underlying CED claims.

5.3. Causal Arrow Entropy (CAE)

Causal Arrow Entropy (CAE) is proposed as a measure of uncertainty in the causal relationship between events:

CAE = H(Event_N | Event_{N-1}, ..., Event_0)

where H represents conditional entropy, measuring the information needed to describe Event_N given knowledge of previous events.

CAE provides a reference for understanding causal structure:

- o Low CAE: The event is highly predictable from previous events, indicating strong causal continuity

- o High CAE: The event introduces significant new information, potentially indicating a causal branch or novel input

Implementations MAY use CAE as a heuristic for detecting causal anomalies or for auditing decision processes.

5.4. Verifiable Delay Function (VDF) Reference

A Verifiable Delay Function (VDF) is a function that requires a minimum number of sequential steps to evaluate, yet produces a proof that can be verified efficiently. VDFs provide a mechanism for demonstrating that a minimum amount of sequential computation has occurred.

In the CTP framework, VDFs MAY be used to provide verifiable evidence of computational expenditure:

- o When an AI system claims a certain cognitive duration (high CED), VDF proofs can support that claim

- o VDF proofs can be verified without re-executing the computation

- o VDFs provide a cryptographic link between claimed cognitive time and actual sequential computation

VDFs are OPTIONAL in CTP implementations. When used, they SHOULD follow established VDF specifications [VDF].

5.5. Judgment Hash Chain

A judgment hash chain is a cryptographic structure linking cognitive events in an ordered sequence:

```
Event_N = {
    content: event data,
    prev_hash: Hash(Event_{N-1}),
    timestamp: reference time,
    metadata: additional information
}
```

The hash chain provides:

- o Integrity: Any modification to a previous event breaks the chain
- o Ordering: The chain establishes an unambiguous sequence
- o Non-repudiation: Events cannot be inserted or removed without detection

Implementations MAY use hash chains to establish causal ordering, particularly for applications requiring auditability (e.g., regulatory compliance, legal proceedings).

6. Layer Relationships

The layers may be considered conceptually hierarchical, with each higher layer building upon concepts introduced in lower layers:

1. Layer 1 (Perception) builds on the definition of time from Layer 0
2. Layer 2 (Direction) builds on the ability to perceive time
3. Layer 3 (Copy) builds on the ability to direct time
4. Layer 4 (Emergence) builds on the ability to copy time

However, these are conceptual dependencies, not implementation requirements. Implementations are free to:

- o Implement a subset of layers
- o Combine layers in different ways
- o Add custom extensions beyond the defined layers
- o Interpret layer concepts according to their specific needs

The layered architecture can be visualized as follows:

```
+---------------------------------------------------+
| Layer 4: Time Emergence (CTP/4)                   |
| Emergence of new temporal structures              |
+---------------------------------------------------+
| Layer 3: Time Copy (CTP/3)                        |
| Distribution and replication of cognitive time    |
+---------------------------------------------------+
| Layer 2: Time Direction (CTP/2)                   |
| Causal ordering and directional flow              |
+---------------------------------------------------+
| Layer 1: Time Perception (CTP/1)                  |
| Density modulation (cognitive vs. physical time)  |
+---------------------------------------------------+
| Layer 0: Time Definition (CTP/0) (this document)  |
| Core concepts and architecture                    |
+---------------------------------------------------+
```

7. Protocol Identification

7.1. Domain

Information about the CTP family, including related documents and resources, is available at:

https://time-protocol.org

7.2. Protocol Prefix

All CTP family documents use the prefix "CTP" followed by a layer number (e.g., CTP/0, CTP/1, CTP/2, CTP/3, CTP/4). This naming convention is intended to facilitate identification and cross-referencing.

8. Hardware Trust Considerations

The CTP framework recognizes that hardware-level trust mechanisms can enhance the verifiability of cognitive time claims. This section provides reference considerations for hardware support.

Trusted Execution Environments (TEEs) (for example, Intel SGX, AMD SEV, or ARM TrustZone) MAY be used to provide:

- Protected counters that cannot be easily tampered with by software
- Secure generation of VDF proofs
- Isolated execution for critical verification functions
- Tamper-evident storage of audit logs

Reference Instruction Set: Implementations MAY consider the following instruction types for hardware support:

- SYNC_COGNITIVE_CLOCK: Retrieve certified time and counter values
- VDF_ITERATE: Perform VDF iterations within protected environment
- EXTEND_HASH_CHAIN: Securely extend cryptographic chains
- ANCHOR_BRANCH: Record branch state in protected storage

These instructions are reference suggestions, not requirements. Hardware support is OPTIONAL and implementation-dependent.

9. Security Considerations

This document describes a conceptual architectural framework. Security considerations for specific implementations or protocols based on this framework SHOULD be addressed in their respective documents.

General security considerations for CTP implementations include:

Verification Integrity:
If verification mechanisms (such as VDFs or hash chains) are used, they SHOULD be implemented correctly to maintain their security properties. Weak implementations might allow circumvention of verification.

Audit Protection:
Systems that maintain audit logs SHOULD protect those logs from unauthorized modification or deletion. Hardware trust mechanisms MAY be used for this purpose.

Privacy:
Cognitive time information might reveal patterns of system behavior. Implementations SHOULD consider privacy implications and provide appropriate access controls.

Denial of Service:
Verification mechanisms SHOULD be designed to resist denial-of-service attacks. Lightweight verification procedures might help maintain system availability.

Key Management:
If cryptographic signatures are used, proper key management practices SHOULD be followed. Keys used for event signing SHOULD be protected from unauthorized access.

10. IANA Considerations

This document has no IANA actions. Future specifications in the CTP family MAY request IANA registrations as needed (e.g., for protocol identifiers, port numbers, or media types).

11. References

11.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

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11.2. Informative References

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