# JANUS
## Rust-First ML Implementation

*End-to-End Machine Learning with Rust*
*FastAPI Gateway & Batch Processing Architecture*

**Classification: Architecture & Implementation Strategy**

**Version: 1.0**

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**Migration Philosophy:**

• **Core ML in Rust:** Maximum performance, safety, and type guarantees

• **Python Gateway:** FastAPI for orchestration and API surface

• **Hybrid Approach:** Use best tool for each layer

• **Modern Stack:** Latest technologies (Candle, ONNX, Burn, tch-rs)

# Abstract

This document outlines a comprehensive strategy for implementing the JANUS trading system with a **Rust-first approach to machine learning**, while maintaining a Python FastAPI gateway for orchestration and external API exposure. The architecture leverages Rust's performance, memory safety, and type system for the entire ML pipeline—from data preprocessing to inference—while using Python strategically for high-level coordination, batch job scheduling, and developer-friendly interfaces.

**Key architectural decisions:**

- **Hot path (Forward):** Pure Rust with ONNX Runtime or tch-rs for <100ms latency

- **Cold path (Backward):** Rust core with optional Python for experimentation

- **Gateway:** FastAPI service exposing REST/gRPC APIs

- **Batch processing:** Rust workers with async job queue

- **Training:** Hybrid Python (PyTorch) to Rust (ONNX/tch-rs) pipeline
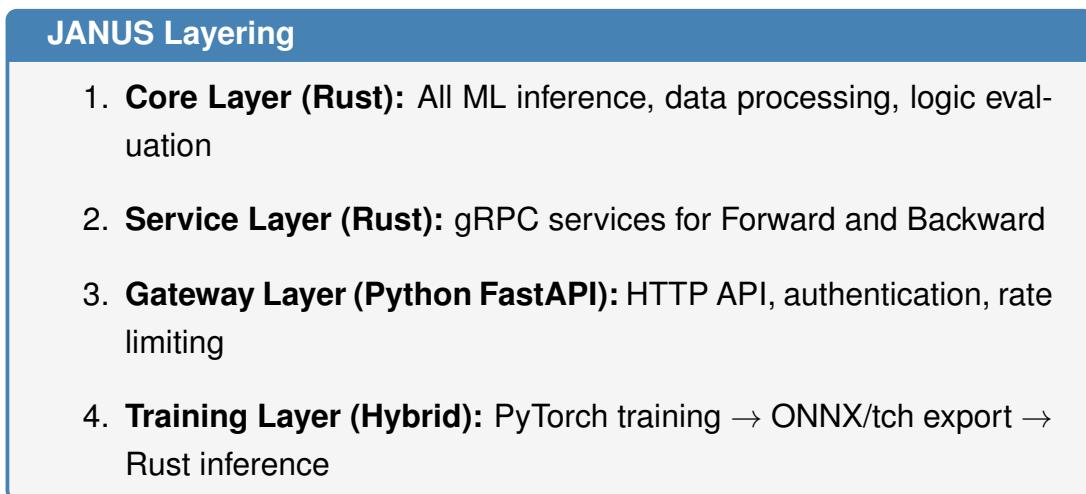
This approach maximizes performance and safety while maintaining ecosystem compatibility and developer productivity.

# Contents
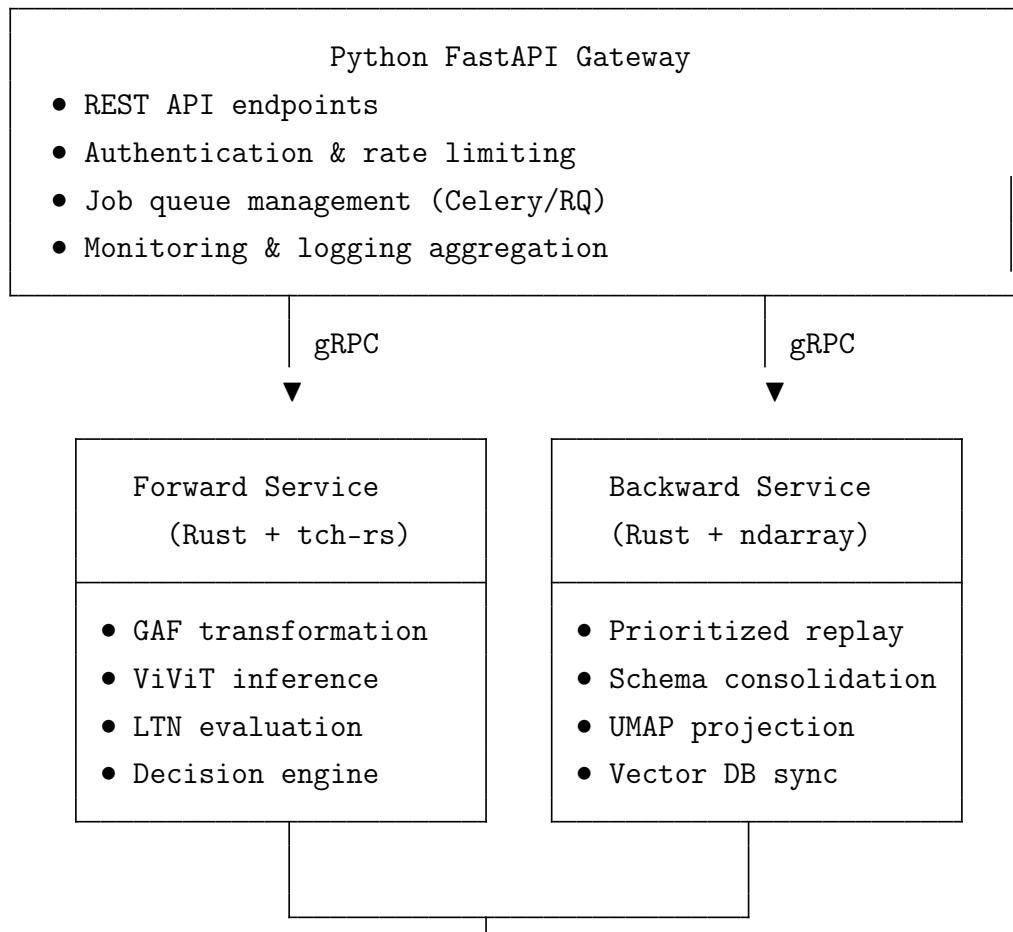
# 1 Architectural Overview
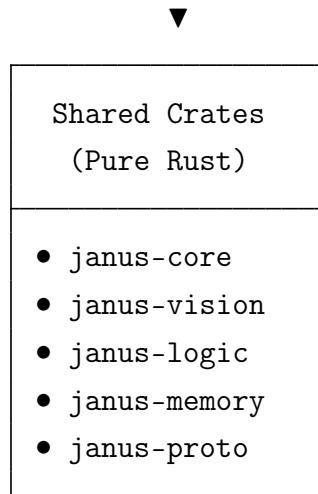
## 1.1 The Rust-First Philosophy

Traditional ML systems place Python at the center, with C++/Rust used only for performance-critical bottlenecks. JANUS inverts this model:

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**JANUS Layering**

1. **Core Layer (Rust):** All ML inference, data processing, logic evaluation

2. **Service Layer (Rust):** gRPC services for Forward and Backward

3. **Gateway Layer (Python FastAPI):** HTTP API, authentication, rate limiting

4. **Training Layer (Hybrid):** PyTorch training $\rightarrow$ ONNX/tch export $\rightarrow$ Rust inference

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## 1.2 Component Diagram

```
                Python FastAPI Gateway
 • REST API endpoints
 • Authentication & rate limiting
 • Job queue management (Celery/RQ)
 • Monitoring & logging aggregation
```

gRPC         gRPC

```
     Forward Service              Backward Service
      (Rust + tch-rs)              (Rust + ndarray)

  • GAF transformation         • Prioritized replay
  • ViViT inference            • Schema consolidation
  • LTN evaluation             • UMAP projection
  • Decision engine            • Vector DB sync
```

▼

```
┌─────────────────────────────┐
│                             │
│      Shared Crates          │
│      (Pure Rust)            │
│                             │
├─────────────────────────────┤
│                             │
│  • janus-core               │
│  • janus-vision             │
│  • janus-logic              │
│  • janus-memory             │
│  • janus-proto              │
│                             │
└─────────────────────────────┘
```

## 1.3   Design Principles

1. **Rust Everywhere Possible**

   - All inference, data transformation, and business logic in Rust

   - Zero-copy operations where possible

   - Compile-time guarantees for correctness

2. **Python as Orchestration Layer**

   - FastAPI for HTTP endpoints and developer UX

   - Async job scheduling (Celery, Dramatiq, or Python RQ)

   - High-level monitoring and alerting

3. **gRPC for Internal Communication**

   - Type-safe, efficient service-to-service communication

   - Shared protobuf definitions in `janus-proto`

   - Streaming support for real-time data

4. **Gradual Migration Strategy**

   - Start with inference in Rust (ONNX models)

   - Migrate data preprocessing incrementally

   - Keep training in PyTorch initially, export to Rust

   - Eventually move training to Rust (Burn/Candle)

# 2 Machine Learning Framework Strategy

## 2.1 Framework Comparison Matrix

| Framework | Pros | Cons | Use Case |
| --- | --- | --- | --- |
| **tch-rs** | Full PyTorch bindings, mature, GPU support | Requires LibTorch, C++ dependency | **Phase 1: Inference** |
| **ONNX Runtime** | Lightweight, optimized, cross-platform | Inference only, limited operators | **Phase 1: Production** |
| **Candle (HF)** | Pure Rust, no C++ deps, growing ecosystem | Young, fewer pre-trained models | **Phase 2: Long-term** |
| **Burn** | Backend-agnostic, autodiff, training support | Early stage, limited models | **Phase 3: Full Rust** |
| **ndarray** | NumPy-like API, stable, CPU optimized | No GPU, no autodiff | **Data processing** |

Table 1: Rust ML Framework Comparison

## 2.2 Recommended Migration Path

### 2.2.1 Phase 1: Hybrid (Months 1-3)

- **Training:** PyTorch on GPU cluster

- **Export:** `torch.onnx.export()` or `torch.jit.save()`

- **Inference:** ONNX Runtime (`ort`) or tch-rs in Rust services

- **Why:** Fastest path to production, leverage existing PyTorch ecosystem

### 2.2.2 Phase 2: Rust-Native Inference (Months 4-6)

- **Training:** Still PyTorch

- **Export:** Candle-compatible checkpoints

- **Inference:** Candle or custom Rust implementations

- **Why:** Eliminate LibTorch dependency, reduce binary size

### 2.2.3   Phase 3: Full Rust ML (Months 7-12)

- **Training:** Burn or Candle with custom training loops

- **Inference:** Same framework as training

- **Why:** Complete type safety, no Python GIL, full control

## 2.3   Framework Selection by Component

| Component | Framework (Phase 1) | Framework (Phase 3) |
|---|---|---|
| GAF Transformation | `ndarray` | `ndarray` or `candle` |
| ViViT Inference | `ort` (ONNX) | `candle` |
| LTN Predicates | `tch-rs` | `candle` |
| Chronos-Bolt | `ort` (ONNX) | `candle` |
| FinBERT | `ort` (ONNX) | `candle-transformers` |
| Decision Engine | `tch-rs` | `burn` |
| PER Buffer | Custom Rust | Custom Rust |
| UMAP | `linfa-reduction` | `linfa-reduction` |

Table 2: Component-Level Framework Selection

# 3   Forward Service: Rust Implementation

## 3.1   Performance Requirements

- **End-to-end latency:** <100ms (target: 50ms)

- **Throughput:** >100 requests/second

- **Memory:** <2GB per instance

- **CPU:** Efficient use of multi-core (no GIL)

## 3.2   Core Data Structures

```
// janus-core/src/types.rs
use ndarray::{Array1, Array2, Array3};

#[derive(Clone, Debug, serde::Serialize, serde::Deserialize)]
pub struct MarketState {
    pub timestamp: i64,
```

```rust
 7      pub price_series: Array1<f32>,  // Last N prices
 8      pub volume_series: Array1<f32>, // Last N volumes
 9      pub lob_snapshot: LimitOrderBook,
10      pub vpin: f32,
11      pub volatility: f32,
12  }
13
14  #[derive(Clone, Debug)]
15  pub struct LimitOrderBook {
16      pub bids: Vec<(f32, f32)>,  // (price, size)
17      pub asks: Vec<(f32, f32)>,
18  }
19
20  #[derive(Clone, Debug)]
21  pub enum Action {
22      Buy { size: f32 },
23      Sell { size: f32 },
24      Hold,
25  }
26
27  #[derive(Clone, Debug)]
28  pub struct Decision {
29      pub action: Action,
30      pub confidence: f32,
31      pub ltn_satisfaction: f32,
32      pub risk_score: f32,
33      pub metadata: HashMap<String, f32>,
34  }
```

## 3.3  GAF Transformation Module

```rust
 1  // janus-vision/src/gaf.rs
 2  use ndarray::{Array1, Array2};
 3
 4  pub struct GafTransformer {
 5      alpha: f32,  // Learnable normalization param
 6      beta: f32,   // Learnable normalization param
 7  }
 8
 9  impl GafTransformer {
```

```rust
10    pub fn transform(&self, series: &Array1<f32>) -> (Array2<f32>,
          Array2<f32>) {
11        // Step 1: Normalize to [-1, 1]
12        let min = series.iter().cloned().fold(f32::INFINITY, f32::
              min);
13        let max = series.iter().cloned().fold(f32::NEG_INFINITY,
              f32::max);
14        let normalized = series.mapv(|x| {
15            let norm = (x - min) / (max - min + 1e-8);
16            (norm * self.alpha + self.beta).tanh()
17        });
18
19        // Step 2: Polar coordinates
20        let phi = normalized.mapv(|x| x.acos());
21
22        // Step 3: Gramian fields
23        let n = series.len();
24        let mut gasf = Array2::<f32>::zeros((n, n));
25        let mut gadf = Array2::<f32>::zeros((n, n));
26
27        for i in 0..n {
28            for j in 0..n {
29                gasf[[i, j]] = (phi[i] + phi[j]).cos();
30                gadf[[i, j]] = (phi[i] - phi[j]).sin();
31            }
32        }
33
34        (gasf, gadf)
35    }
36
37    pub fn video(&self, series: &Array1<f32>, window: usize, stride
          : usize, frames: usize)
38        -> Array3<f32>
39    {
40        let mut video_frames = Vec::new();
41
42        for f in 0..frames {
43            let start = f * stride;
44            let end = start + window;
45            if end > series.len() {
46                break;
```

```
47            }
48            let window_series = series.slice(s![start..end]).
                  to_owned();
49            let (gasf, gadf) = self.transform(&window_series);
50
51            // Stack GASF and GADF as channels
52            video_frames.push(gasf);
53            video_frames.push(gadf);
54        }
55
56        // Stack into 3D tensor: [frames, 2, window, window]
57        stack_frames(&video_frames, frames, window)
58    }
59 }
```

## 3.4 LTN Constraint Evaluation

```
1  // janus-logic/src/ltn.rs
2  use tch::{Tensor, nn};
3
4  pub struct LogicTensorNetwork {
5      predicates: HashMap<String, PredicateNet>,
6  }
7
8  pub struct PredicateNet {
9      model: nn::Sequential,
10 }
11
12 impl PredicateNet {
13     pub fn evaluate(&self, embedding: &Tensor) -> f32 {
14         let logit = self.model.forward(embedding);
15         logit.sigmoid().double_value(&[]) as f32
16     }
17 }
18
19 impl LogicTensorNetwork {
20     pub fn check_wash_sale(&self, action: &Action, history: &[
            Action]) -> f32 {
21         // Encode wash sale constraint
22         //  t ,  k  in [1,30]: not(SaleAtLoss(t) and Buy(t+k))
23         let mut min_satisfaction = 1.0;
```

```rust
        // Implementation of  ukasiewicz  t-norm
        for (t, past_action) in history.iter().enumerate() {
            if let Action::Sell { .. } = past_action {
                if is_loss(past_action) {
                    for k in 1..=30 {
                        if t + k < history.len() {
                            if let Action::Buy { .. } = &history[t
                                + k] {
                                //  ukasiewicz  conjunction: max(0,
                                    a + b - 1)
                                let conjunction = (1.0 + 1.0 - 1.0)
                                    .max(0.0);
                                // Negation: 1 - conjunction
                                let satisfaction = 1.0 -
                                    conjunction;
                                min_satisfaction = min_satisfaction
                                    .min(satisfaction);
                            }
                        }
                    }
                }
            }
        }

        min_satisfaction
    }

    pub fn check_almgren_chriss(&self, state: &MarketState, action:
        &Action) -> f32 {
        let volatility = state.volatility;
        let avg_volume = state.volume_series.mean().unwrap();

        match action {
            Action::Buy { size } | Action::Sell { size } => {
                let eta = 0.1;  // Market impact coefficient
                let threshold = eta * volatility * (size /
                    avg_volume).sqrt();

                // If impact < threshold, satisfaction = 1.0
                // Smooth approximation with sigmoid
```

```
58              let impact_ratio = size / (avg_volume * threshold);
59              1.0 - impact_ratio.min(1.0)
60          }
61          Action::Hold => 1.0,
62      }
63  }
64
65  pub fn check_vpin(&self, state: &MarketState) -> f32 {
66      let vpin_threshold = 0.7;
67
68      // If VPIN > threshold, should halt trading
69      if state.vpin > vpin_threshold {
70          0.0  // Constraint violated
71      } else {
72          1.0  // Constraint satisfied
73      }
74  }
75
76  pub fn evaluate_all(&self, state: &MarketState, action: &Action
        , history: &[Action]) -> f32 {
77      let wash_sale = self.check_wash_sale(action, history);
78      let almgren = self.check_almgren_chriss(state, action);
79      let vpin = self.check_vpin(state);
80
81      // Generalized mean (p=2 for quadratic mean)
82      let constraints = vec![wash_sale, almgren, vpin];
83      let sum_squared: f32 = constraints.iter().map(|x| x.powi(2)
            ).sum();
84      (sum_squared / constraints.len() as f32).sqrt()
85  }
86 }
```

## 3.5  Model Inference with ONNX Runtime

```
1  // janus-vision/src/vivit.rs
2  use ort::{Environment, Session, SessionBuilder, Value};
3  use ndarray::Array4;
4
5  pub struct ViViTInference {
6      session: Session,
7      env: Arc<Environment>,
```

```rust
8  }
9
10 impl ViViTInference {
11     pub fn new(model_path: &str) -> Result<Self, ort::OrtError> {
12         let env = Arc::new(Environment::builder().build()?);
13         let session = SessionBuilder::new(&env)?
14             .with_optimization_level(ort::GraphOptimizationLevel::
                   Level3)?
15             .with_intra_threads(4)?
16             .with_model_from_file(model_path)?;
17
18         Ok(Self { session, env })
19     }
20
21     pub fn infer(&self, video: &Array4<f32>) -> Result<Array1<f32>,
           ort::OrtError> {
22         // Convert ndarray to ONNX tensor
23         let input_tensor = Value::from_array(self.session.allocator
               (), video)?;
24
25         // Run inference
26         let outputs = self.session.run(vec![input_tensor])?;
27
28         // Extract output
29         let output_tensor = outputs[0].try_extract()?;
30         let embedding = output_tensor.view().to_owned();
31
32         Ok(embedding)
33     }
34 }
```

## 3.6  Async Service with Tokio

```rust
1  // services/forward/src/main.rs
2  use tonic::{transport::Server, Request, Response, Status};
3  use janus_proto::forward_service_server::{ForwardService,
      ForwardServiceServer};
4  use janus_proto::{DecisionRequest, DecisionResponse};
5
6  pub struct ForwardServiceImpl {
7      gaf_transformer: Arc<GafTransformer>,
```

12

```rust
 8      vivit_model: Arc<ViViTInference>,
 9      ltn: Arc<LogicTensorNetwork>,
10      decision_engine: Arc<DecisionEngine>,
11  }
12
13  #[tonic::async_trait]
14  impl ForwardService for ForwardServiceImpl {
15      async fn get_decision(
16          &self,
17          request: Request<DecisionRequest>,
18      ) -> Result<Response<DecisionResponse>, Status> {
19          let req = request.into_inner();
20
21          // Parse market state
22          let state = parse_market_state(&req)?;
23
24          // 1. GAF transformation
25          let video = self.gaf_transformer.video(
26              &state.price_series,
27              60,  // window
28              10,  // stride
29              16,  // frames
30          );
31
32          // 2. ViViT inference
33          let visual_embedding = self.vivit_model.infer(&video)
34              .map_err(|e| Status::internal(format!("ViViT inference
                  failed: {}", e)))?;
35
36          // 3. LTN evaluation
37          let ltn_satisfaction = self.ltn.evaluate_all(&state, &
              Action::Hold, &[]);
38
39          // 4. Decision engine
40          let decision = self.decision_engine.decide(
41              &state,
42              &visual_embedding,
43              ltn_satisfaction,
44          )?;
45
46          // 5. Build response
```

```
47        let response = DecisionResponse {
48            action: decision.action.to_string(),
49            confidence: decision.confidence,
50            ltn_satisfaction: decision.ltn_satisfaction,
51            risk_score: decision.risk_score,
52            metadata: decision.metadata,
53        };
54
55        Ok(Response::new(response))
56    }
57 }
58
59 #[tokio::main]
60 async fn main() -> Result<(), Box<dyn std::error::Error>> {
61     let addr = "0.0.0.0:50051".parse()?;
62
63     let service = ForwardServiceImpl {
64         gaf_transformer: Arc::new(GafTransformer::new(1.0, 0.0)),
65         vivit_model: Arc::new(ViViTInference::new("models/vivit.
               onnx")?),
66         ltn: Arc::new(LogicTensorNetwork::load("models/ltn")?),
67         decision_engine: Arc::new(DecisionEngine::new()),
68     };
69
70     println!("Forward␣service␣listening␣on␣{}", addr);
71
72     Server::builder()
73         .add_service(ForwardServiceServer::new(service))
74         .serve(addr)
75         .await?;
76
77     Ok(())
78 }
```

# 4  Backward Service: Batch Processing

## 4.1  Performance Requirements

- **Latency:** Not critical (batch processing)

- **Throughput:** Process 10k-100k transitions per sleep cycle

- **Memory:** Can use up to 16GB for large batches

- **Parallelism:** Leverage all CPU cores with Rayon

## 4.2  Prioritized Experience Replay

```rust
// janus-memory/src/replay.rs
use rayon::prelude::*;
use rand::distributions::WeightedIndex;
use rand::prelude::*;

pub struct PrioritizedReplayBuffer {
    buffer: Vec<Transition>,
    priorities: Vec<f32>,
    capacity: usize,
    alpha: f32,  // Prioritization exponent
    beta: f32,   // Importance sampling correction
}

impl PrioritizedReplayBuffer {
    pub fn sample(&self, batch_size: usize) -> (Vec<Transition>,
        Vec<f32>) {
        let probabilities: Vec<f32> = self.priorities
            .iter()
            .map(|p| p.powf(self.alpha))
            .collect();

        let total: f32 = probabilities.iter().sum();
        let normalized_probs: Vec<f32> = probabilities
            .iter()
            .map(|p| p / total)
            .collect();

        let dist = WeightedIndex::new(&normalized_probs).unwrap();
        let mut rng = thread_rng();

        let indices: Vec<usize> = (0..batch_size)
            .map(|_| dist.sample(&mut rng))
            .collect();

        // Compute importance sampling weights
        let n = self.buffer.len() as f32;
```

```rust
36      let weights: Vec<f32> = indices
37          .iter()
38          .map(|&i| {
39              let prob = normalized_probs[i];
40              ((1.0 / n) * (1.0 / prob)).powf(self.beta)
41          })
42          .collect();
43
44      // Normalize weights
45      let max_weight = weights.iter().cloned().fold(f32::
            NEG_INFINITY, f32::max);
46      let normalized_weights: Vec<f32> = weights
47          .iter()
48          .map(|w| w / max_weight)
49          .collect();
50
51      let transitions: Vec<Transition> = indices
52          .iter()
53          .map(|&i| self.buffer[i].clone())
54          .collect();
55
56      (transitions, normalized_weights)
57  }
58
59  pub fn update_priorities(&mut self, indices: Vec<usize>,
        td_errors: Vec<f32>,
60                           logic_violations: Vec<f32>, rewards:
                                Vec<f32>) {
61      for (idx, (&i, (&td, (&vio, &rew)))) in indices.iter()
62          .zip(td_errors.iter()
63              .zip(logic_violations.iter()
64                  .zip(rewards.iter())))
65          .enumerate()
66      {
67          // Priority = |TD-error| +  _logic  * violation +
                _reward  * |reward|
68          self.priorities[i] = td.abs() + 2.0 * vio + 0.5 * rew.
                abs();
69      }
70  }
71 }
```

## 4.3   Schema Consolidation

```rust
// janus-memory/src/schema.rs
use ndarray::{Array1, Array2};

pub struct SchemaMemory {
    schemas: Vec<Schema>,
    recall_threshold: f32,
    logic_threshold: f32,
}

impl SchemaMemory {
    pub fn consolidate(&mut self, transitions: &[Transition], ltn:
        &LogicTensorNetwork) {
        for transition in transitions {
            // Compute gates
            let recall_gate = self.compute_recall_gate(&transition.
                state);
            let logic_gate = ltn.evaluate_all(&transition.state, &
                transition.action, &[]);

            // Only consolidate if both gates pass
            if recall_gate > self.recall_threshold && logic_gate >
                self.logic_threshold {
                // Find best matching schema
                let (best_idx, best_likelihood) = self.
                    find_best_schema(&transition.state);

                if best_likelihood < 0.01 {
                    // Create new schema
                    self.create_schema(&transition.state);
                } else {
                    // Update existing schema
                    self.update_schema(best_idx, &transition.state,
                        0.01);
                }
            }
        }
    }

    fn update_schema(&mut self, idx: usize, state: &Array1<f32>, lr
        : f32) {
```

```rust
34        let schema = &mut self.schemas[idx];
35
36        // Update mean:    = (1-  )   +   *x
37        let diff = state - &schema.mean;
38        schema.mean = &schema.mean + lr * &diff;
39
40        // Update covariance:    = (1-  )   +   *(x-  )(x-  )
41        let outer = outer_product(&diff, &diff);
42        schema.covariance = (1.0 - lr) * &schema.covariance + lr *
              outer;
43
44        schema.num_points += 1;
45    }
46 }
```

## 4.4 Parallel Sleep Cycle

```rust
1  // services/backward/src/sleep_cycle.rs
2  use rayon::prelude::*;
3
4  pub async fn run_sleep_cycle(
5      replay_buffer: &mut PrioritizedReplayBuffer,
6      schema_memory: &mut SchemaMemory,
7      ltn: &LogicTensorNetwork,
8      policy: &mut Policy,
9  ) -> Result<SleepCycleMetrics, BackwardError> {
10     let start = std::time::Instant::now();
11     let mut metrics = SleepCycleMetrics::default();
12
13     // Phase 1: Prioritized Replay (1000 iterations)
14     for iteration in 0..1000 {
15         let (batch, weights) = replay_buffer.sample(256);
16
17         // Parallel TD-error computation
18         let td_errors: Vec<f32> = batch.par_iter()
19             .map(|transition| compute_td_error(transition, policy))
20             .collect();
21
22         // Parallel logic violation scoring
23         let violations: Vec<f32> = batch.par_iter()
24             .map(|transition| {
```

```
25              1.0 - ltn.evaluate_all(&transition.state, &
                    transition.action, &[])
26          })
27          .collect();
28
29      // Update policy with importance-weighted gradients
30      policy.update(&batch, &weights);
31
32      // Update priorities
33      let rewards: Vec<f32> = batch.iter().map(|t| t.reward).
            collect();
34      let indices: Vec<usize> = (0..batch.len()).collect();
35      replay_buffer.update_priorities(indices, td_errors,
            violations, rewards);
36
37      if iteration % 100 == 0 {
38          println!("Replay␣iteration␣{}/1000", iteration);
39      }
40  }
41
42  // Phase 2: Schema Consolidation
43  let all_transitions: Vec<Transition> = replay_buffer.buffer.
        clone();
44  schema_memory.consolidate(&all_transitions, ltn);
45  metrics.num_schemas = schema_memory.schemas.len();
46
47  // Phase 3: UMAP Update
48  let embeddings = extract_schema_embeddings(schema_memory);
49  let umap_projection = fit_aligned_umap(&embeddings)?;
50  metrics.num_clusters = detect_clusters(&umap_projection);
51
52  // Phase 4: Vector DB Sync
53  sync_to_qdrant(schema_memory).await?;
54
55  metrics.duration = start.elapsed();
56  Ok(metrics)
```

# 5 Python FastAPI Gateway

## 5.1 Architecture Purpose

The Python gateway serves as:

- **API Surface:** User-friendly REST endpoints

- **Authentication:** JWT tokens, API key validation

- **Rate Limiting:** Per-user request throttling

- **Job Scheduling:** Async batch processing with Celery/Dramatiq

- **Monitoring:** Metrics aggregation and alerting

## 5.2 FastAPI Service Implementation

```python
1  # gateway/main.py
2  from fastapi import FastAPI, Depends, HTTPException,
       BackgroundTasks
3  from fastapi.security import HTTPBearer,
       HTTPAuthorizationCredentials
4  import grpc
5  from pydantic import BaseModel
6  import asyncio
7
8  # Generated from proto files
9  from janus_proto import forward_service_pb2,
       forward_service_pb2_grpc
10 from janus_proto import backward_service_pb2,
       backward_service_pb2_grpc
11
12 app = FastAPI(title="JANUS Trading System API")
13 security = HTTPBearer()
14
15 # gRPC channel pool
16 forward_channel = grpc.aio.insecure_channel('forward-service:50051'
       )
17 backward_channel = grpc.aio.insecure_channel('backward-service
       :50052')
18
19 forward_stub = forward_service_pb2_grpc.ForwardServiceStub(
       forward_channel)
20 backward_stub = backward_service_pb2_grpc.BackwardServiceStub(
       backward_channel)
```

```python
class MarketStateRequest(BaseModel):
    timestamp: int
    price_series: list[float]
    volume_series: list[float]
    lob_bids: list[tuple[float, float]]
    lob_asks: list[tuple[float, float]]

class DecisionResponse(BaseModel):
    action: str
    confidence: float
    ltn_satisfaction: float
    risk_score: float
    latency_ms: float

@app.post("/api/v1/decision", response_model=DecisionResponse)
async def get_trading_decision(
    request: MarketStateRequest,
    credentials: HTTPAuthorizationCredentials = Depends(security)
):
    """Get real-time trading decision from Forward service."""
    # Authenticate
    validate_token(credentials.credentials)

    # Convert to protobuf
    grpc_request = forward_service_pb2.DecisionRequest(
        timestamp=request.timestamp,
        price_series=request.price_series,
        volume_series=request.volume_series,
        # ... other fields
    )

    # Call Rust Forward service via gRPC
    start = asyncio.get_event_loop().time()
    try:
        grpc_response = await forward_stub.GetDecision(grpc_request
            )
    except grpc.RpcError as e:
        raise HTTPException(status_code=503, detail=f"Forward
            service unavailable: {e}")
```

```python
60      latency = (asyncio.get_event_loop().time() - start) * 1000
61
62      return DecisionResponse(
63          action=grpc_response.action,
64          confidence=grpc_response.confidence,
65          ltn_satisfaction=grpc_response.ltn_satisfaction,
66          risk_score=grpc_response.risk_score,
67          latency_ms=latency,
68      )
69
70  @app.post("/api/v1/sleep-cycle")
71  async def trigger_sleep_cycle(background_tasks: BackgroundTasks):
72      """Trigger memory consolidation (runs asynchronously)."""
73      # Enqueue background job
74      background_tasks.add_task(run_sleep_cycle_job)
75      return {"status": "sleep_cycle_queued", "job_id": "unique-job-
            id"}
76
77  async def run_sleep_cycle_job():
78      """Background task that calls Backward service."""
79      grpc_request = backward_service_pb2.SleepCycleRequest()
80
81      try:
82          grpc_response = await backward_stub.RunSleepCycle(
               grpc_request)
83          print(f"Sleep cycle completed: {grpc_response.num_schemas} 
               schemas")
84      except grpc.RpcError as e:
85          print(f"Sleep cycle failed: {e}")
86
87  # Monitoring endpoints
88  @app.get("/api/v1/health")
89  async def health_check():
90      """Health check endpoint."""
91      return {
92          "status": "healthy",
93          "forward_service": await check_forward_health(),
94          "backward_service": await check_backward_health(),
95      }
96
97  @app.get("/api/v1/metrics")
```

```
98  async def get_metrics():
99      """Prometheus metrics endpoint."""
100     # Aggregate metrics from Rust services
101     forward_metrics = await forward_stub.GetMetrics(empty_pb2.Empty
            ())
102     backward_metrics = await backward_stub.GetMetrics(empty_pb2.
            Empty())
103
104     return {
105         "forward": forward_metrics,
106         "backward": backward_metrics,
107     }
```

## 5.3  Batch Job Processing with Celery

```
1   # gateway/tasks.py
2   from celery import Celery
3   import grpc
4
5   celery_app = Celery('janus', broker='redis://localhost:6379/0')
6
7   @celery_app.task(bind=True, max_retries=3)
8   def run_sleep_cycle(self):
9       """Celery task for long-running sleep cycle."""
10      channel = grpc.insecure_channel('backward-service:50052')
11      stub = backward_service_pb2_grpc.BackwardServiceStub(channel)
12
13      try:
14          request = backward_service_pb2.SleepCycleRequest()
15          response = stub.RunSleepCycle(request)
16
17          return {
18              "status": "success",
19              "num_schemas": response.num_schemas,
20              "duration_seconds": response.duration_seconds,
21          }
22      except grpc.RpcError as e:
23          # Retry on failure
24          raise self.retry(exc=e, countdown=60)
25
26  @celery_app.task
```

```python
27  def backtest_strategy(start_date: str, end_date: str):
28      """Long-running backtesting job."""
29      # Call Backward service for historical simulation
30      # This can take hours, so runs in background
31      pass
```

# 6 Hybrid Training Pipeline

## 6.1 PyTorch Training (Phase 1)

```python
1  # training/train_vivit.py
2  import torch
3  import torch.nn as nn
4  from torch.utils.data import DataLoader
5
6  class ViViTTrainer:
7      def __init__(self, model, device='cuda'):
8          self.model = model.to(device)
9          self.device = device
10         self.optimizer = torch.optim.AdamW(model.parameters(), lr=1
             e-4)
11
12     def train_epoch(self, dataloader):
13         self.model.train()
14         total_loss = 0
15
16         for batch in dataloader:
17             videos, labels = batch
18             videos = videos.to(self.device)
19             labels = labels.to(self.device)
20
21             # Forward pass
22             outputs = self.model(videos)
23             loss = nn.CrossEntropyLoss()(outputs, labels)
24
25             # Backward pass
26             self.optimizer.zero_grad()
27             loss.backward()
28             self.optimizer.step()
29
```

```
30            total_loss += loss.item()
31
32        return total_loss / len(dataloader)
33
34    def export_to_onnx(self, path: str):
35        """Export trained model to ONNX for Rust inference."""
36        self.model.eval()
37        dummy_input = torch.randn(1, 16, 2, 60, 60).to(self.device)
38
39        torch.onnx.export(
40            self.model,
41            dummy_input,
42            path,
43            export_params=True,
44            opset_version=14,
45            do_constant_folding=True,
46            input_names=['video'],
47            output_names=['embedding'],
48            dynamic_axes={
49                'video': {0: 'batch_size'},
50                'embedding': {0: 'batch_size'}
51            }
52        )
53        print(f"Model exported to {path}")
54
55 # Usage
56 trainer = ViViTTrainer(model)
57 for epoch in range(100):
58     loss = trainer.train_epoch(train_loader)
59     print(f"Epoch {epoch}: Loss = {loss}")
60
61 # Export to ONNX
62 trainer.export_to_onnx("models/vivit.onnx")
```

## 6.2  Model Export & Validation

```
1 # training/validate_export.py
2 import torch
3 import onnx
4 import onnxruntime as ort
5 import numpy as np
```

```python
6
7   def validate_onnx_export(pytorch_model, onnx_path):
8       """Validate that ONNX export matches PyTorch output."""
9
10      # Load ONNX model
11      onnx_model = onnx.load(onnx_path)
12      onnx.checker.check_model(onnx_model)
13
14      # Create ONNX Runtime session
15      ort_session = ort.InferenceSession(onnx_path)
16
17      # Test input
18      dummy_input = torch.randn(1, 16, 2, 60, 60)
19
20      # PyTorch inference
21      pytorch_model.eval()
22      with torch.no_grad():
23          pytorch_output = pytorch_model(dummy_input).numpy()
24
25      # ONNX inference
26      ort_inputs = {ort_session.get_inputs()[0].name: dummy_input.
            numpy()}
27      onnx_output = ort_session.run(None, ort_inputs)[0]
28
29      # Compare outputs
30      diff = np.abs(pytorch_output - onnx_output).max()
31      print(f"Max difference: {diff}")
32
33      if diff < 1e-5:
34          print("[OK] ONNX export validated successfully")
35      else:
36          print("[FAIL] ONNX export validation failed")
37
38  validate_onnx_export(model, "models/vivit.onnx")
```

# 7  Deployment Architecture

## 7.1  Docker Compose Setup

```yaml
1   # docker-compose.yml
```

```yaml
version: '3.8'

services:
  gateway:
    build: ./gateway
    ports:
      - "8000:8000"
    environment:
      - FORWARD_SERVICE_URL=forward:50051
      - BACKWARD_SERVICE_URL=backward:50052
    depends_on:
      - forward
      - backward
      - redis

  forward:
    build: ./services/forward
    ports:
      - "50051:50051"
    volumes:
      - ./models:/models:ro
    environment:
      - RUST_LOG=info
      - MODEL_PATH=/models/vivit.onnx
    deploy:
      resources:
        limits:
          cpus: '4'
          memory: 2G

  backward:
    build: ./services/backward
    ports:
      - "50052:50052"
    volumes:
      - ./models:/models:ro
      - ./data:/data
    environment:
      - RUST_LOG=info
      - QDRANT_URL=http://qdrant:6333
    depends_on:
```

```
43        - qdrant
44
45    qdrant:
46      image: qdrant/qdrant:latest
47      ports:
48        - "6333:6333"
49      volumes:
50        - qdrant_data:/qdrant/storage
51
52    redis:
53      image: redis:7-alpine
54      ports:
55        - "6379:6379"
56
57    celery_worker:
58      build: ./gateway
59      command: celery -A tasks worker --loglevel=info
60      depends_on:
61        - redis
62        - backward
63
64 volumes:
65    qdrant_data:
```

## 7.2  Kubernetes Deployment

```
1  # k8s/forward-deployment.yaml
2  apiVersion: apps/v1
3  kind: Deployment
4  metadata:
5    name: janus-forward
6  spec:
7    replicas: 3
8    selector:
9      matchLabels:
10        app: janus-forward
11    template:
12      metadata:
13        labels:
14          app: janus-forward
15      spec:
```

```
16        containers:
17        - name: forward
18          image: janus/forward:latest
19          ports:
20          - containerPort: 50051
21          resources:
22            requests:
23              memory: "1Gi"
24              cpu: "2"
25            limits:
26              memory: "2Gi"
27              cpu: "4"
28          env:
29          - name: RUST_LOG
30            value: "info"
31          - name: MODEL_PATH
32            value: "/models/vivit.onnx"
33          volumeMounts:
34          - name: models
35            mountPath: /models
36            readOnly: true
37        volumes:
38        - name: models
39          persistentVolumeClaim:
40            claimName: model-storage
41  ---
42  apiVersion: v1
43  kind: Service
44  metadata:
45    name: janus-forward
46  spec:
47    selector:
48      app: janus-forward
49    ports:
50    - protocol: TCP
51      port: 50051
52      targetPort: 50051
53    type: ClusterIP
```

29

# 8 Implementation Roadmap

## 8.1 Phase 1: Foundation (Weeks 1-4)

1. **Week 1: Project Setup**

   ○ Initialize Rust workspace with cargo

   ○ Set up CI/CD (GitHub Actions)

   ○ Create protobuf definitions

   ○ Generate gRPC stubs for Rust and Python

2. **Week 2: Core Crates**

   ○ Implement `janus-core` with domain types

   ○ Implement `janus-vision` GAF transformation

   ○ Add comprehensive unit tests

3. **Week 3: Model Integration**

   ○ Train ViViT model in PyTorch

   ○ Export to ONNX and validate

   ○ Integrate ONNX Runtime in Rust

   ○ Benchmark inference latency

4. **Week 4: Basic Services**

   ○ Implement Forward service skeleton

   ○ Implement Backward service skeleton

   ○ Set up FastAPI gateway

   ○ Test end-to-end flow

## 8.2 Phase 2: Core Features (Weeks 5-8)

1. **Week 5: LTN Implementation**

   ○ Implement Łukasiewicz t-norms

   ○ Encode wash sale constraint

   ○ Encode Almgren-Chriss constraint

   ○ Encode VPIN constraint

2. **Week 6: Decision Engine**

   ○ Implement dual pathway logic

   ○ Add risk gating

   ○ Add logic gating

   ○ Implement cerebellar forward model

3. **Week 7: Memory System**

   ○ Implement episodic buffer

   ○ Implement prioritized replay

   ○ Add schema consolidation

4. **Week 8: Vector Database**

   ○ Set up Qdrant

   ○ Implement schema storage

   ○ Implement similarity search

   ○ Add periodic pruning

## 8.3   Phase 3: Production Readiness (Weeks 9-12)

1. **Week 9: Performance Optimization**

   ○ Profile and optimize hot paths

   ○ Add SIMD optimizations

   ○ Implement model quantization

   ○ Benchmark end-to-end latency

2. **Week 10: Safety & Testing**

   ○ Remove all panic!() calls

   ○ Add comprehensive error handling

   ○ Write integration tests

   ○ Add property-based tests

3. **Week 11: Monitoring & Observability**

   ○ Add Prometheus metrics

   ○ Implement distributed tracing

○ Set up alerting

○ Create dashboards

4. **Week 12: Deployment**

○ Create Docker images

○ Write Kubernetes manifests

○ Set up staging environment

○ Run load tests

# 9 Complete Implementation Checklist

sec:checklist

## 9.1 Infrastructure Setup

○ Create Rust workspace (`Cargo.toml`)

○ Set up monorepo structure (services + crates)

○ Configure CI/CD pipeline

○ Set up Docker build system

○ Configure linting (clippy, rustfmt)

## 9.2 Shared Crates

○ **janus-core**: Domain types, errors, utilities

○ **janus-vision**: GAF, ViViT, image processing

○ **janus-logic**: LTN, constraint evaluation

○ **janus-memory**: Replay buffer, schemas

○ **janus-execution**: Order execution, market simulation

○ **janus-proto**: Protobuf definitions and gRPC stubs

## 9.3   Forward Service (Rust)

○ gRPC server setup with Tonic

○ GAF transformation pipeline

○ ONNX model loading and inference

○ LTN constraint evaluation

○ Multimodal fusion

○ Decision engine with dual pathways

○ Metrics export (Prometheus)

○ Health check endpoint

○ Graceful shutdown

## 9.4   Backward Service (Rust)

○ gRPC server setup

○ Episodic buffer implementation

○ Prioritized replay sampling

○ TD-error computation

○ Schema consolidation

○ UMAP integration

○ Qdrant client and sync

○ Sleep cycle orchestration

○ Parallel batch processing

## 9.5   Gateway Service (Python)

○ FastAPI application setup

○ gRPC client stubs

○ REST endpoints (/decision, /sleep-cycle, etc.)

○ JWT authentication

○ Rate limiting middleware

○ Celery worker setup

○ Background job management

○ Health check aggregation

○ Metrics aggregation

## 9.6  Training Pipeline (Python)

○ PyTorch model definitions

○ Data loaders and preprocessing

○ Training loops

○ ONNX export scripts

○ Export validation

○ Model versioning

## 9.7  Testing

○ Unit tests for all crates

○ Integration tests for services

○ End-to-end tests

○ Load tests

○ Chaos testing

## 9.8  Deployment

○ Docker images for all services

○ Docker Compose for local dev

○ Kubernetes manifests

○ Helm charts

○ Staging environment

○ Production environment

# 10    Conclusion

This Rust-first implementation strategy for JANUS provides:

1. **Maximum Performance**: Rust's zero-cost abstractions and no GIL enable <100ms latency for Forward service

2. **Type Safety**: Compile-time guarantees prevent entire classes of bugs

3. **Memory Safety**: No null pointer dereferences, no data races

4. **Developer Experience**: Python gateway maintains ease of use for API consumers

5. **Ecosystem Compatibility**: Hybrid approach leverages best tools from both ecosystems

**Next Steps:**

- Begin with Phase 1 foundation (weeks 1-4)

- Train initial models in PyTorch and export to ONNX

- Implement Forward service with ONNX Runtime

- Gradually migrate components to pure Rust (Candle/Burn)

- Monitor performance and iterate

The architecture is designed for **incremental migration**, allowing you to start with ONNX inference in Rust while keeping training in PyTorch, then gradually move to a fully Rust-native stack as the ecosystem matures.

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