2025-11-01

section 0

[2em] **Part Overview · Duration:**

Beginner-Friendly Visual Study Guide

subsection 0.0 What You'll Learn

- **Ultimate Orchestrator Pattern**: Coordinate 6 specialized agents for complex tasks
- **Checkpoint System**: Prevent work loss on token limits/crashes
- **Recovery Workflow**: Resume multi-agent tasks across sessions
- **Quality Gates**: Automated validation (8 gates, 7/8 pass required)

subsection 0.0 Why This Matters

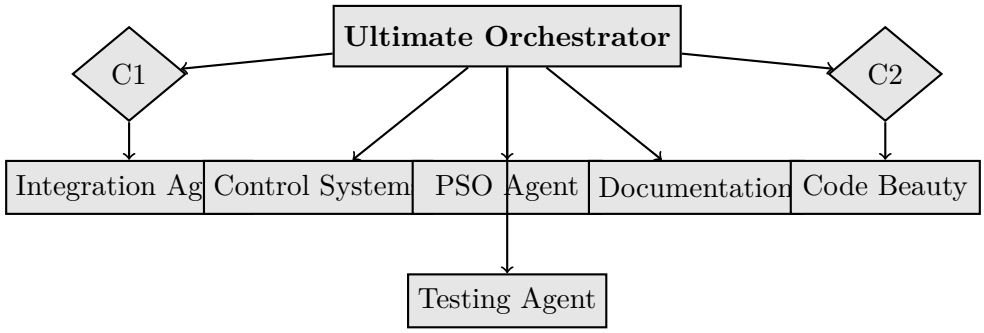
Problem: Large refactorings (e.g., 34-issue UI overhauls) can exceed 200K token limits mid-execution, losing hours of work.

Solution: Checkpoint system + multi-agent orchestration survives crashes and enables resumption with zero context loss.

Impact: Phase 3 UI completion (34 issues) achieved via checkpointed 6-agent orchestration, surviving 3 token limit events.

section 0 The Ultimate Orchestrator Pattern

subsection 0.0 Architecture Overview



subsection 0.0 Agent Roles & Responsibilities

enumi**Integration Agent**: Merge changes across 5+ modules, resolve conflicts

0. enumi**Control Systems Agent**: Implement controllers, validate Lyapunov stability
0. enumi**PSO Agent**: Optimize hyperparameters, run benchmarks
0. enumi**Documentation Agent**: Generate API docs, update guides
0. enumi**Code Beautification Agent**: Apply formatters, fix linting issues
0. enumi**Testing Agent**: Write pytest tests, achieve 95% coverage

subsection 0.0 Orchestrator Responsibilities

0. **Task Decomposition**: Break 34-issue roadmap into 6 agent workstreams

- **Dependency Resolution**: Launch agents in correct order (e.g., Integration before Documentation)
- **Checkpoint Management**: Save agent state every 5-10 minutes
- **Quality Validation**: Run 8 quality gates, fail if <7 pass
- **Recovery Coordination**: Resume from last checkpoint on token limit

section 0 Checkpoint System Architecture

subsection 0.0 Core Concepts

- **Checkpoint**: Snapshot of agent state (task ID, progress, deliverables, current phase)

- **Granularity**: Per-agent, per-task, timestamped
- **Storage**: JSON files in `.ai_workspace/state/checkpoints/`
- **Triggers**: Manual (API call), automatic (every 5-10 min), event-driven (pre-commit)

subsection 0.0 Checkpoint Lifecycle

enumi**Plan Approved**: User approves multi-agent plan, checkpoint created

0. enumi**Agent Launched**: Each agent gets unique checkpoint on spawn
0. enumi**Progress Updates**: Agent reports completion every 5-10 min
0. enumi**Agent Complete/Failed**: Final checkpoint with success/failure status
0. enumi**Recovery**: New session loads latest checkpoints, resumes work

subsection 0.0 Checkpoint Data Structure

```
lstnumber{
lstnumber  "task_id": "LT-4",
lstnumber  "agent_id": "agent_control_systems",
lstnumber  "timestamp": "2025-01-29T17:30:00Z",
lstnumber  "status": "in_progress",
lstnumber  "hours_allocated": 12.0,
lstnumber  "hours_completed": 8.5,
lstnumber  "deliverables_completed": [
lstnumber    "Lyapunov proof for classical SMC",
lstnumber    "Boundary layer optimization"
lstnumber  ],
lstnumber  "current_phase": "Implementing adaptive SMC proofs",
lstnumber  "dependencies": ["agent_pso"],
lstnumber  "artifacts": [
lstnumber    ".artifacts/LT-4/lyapunov_classical.pdf",
lstnumber    ".artifacts/LT-4/boundary_layer_results.json"
lstnumber  ]
lstnumber}
```

section 0 Checkpoint API & Usage

subsection 0.0 Mandatory Checkpoint Calls

```
lstnumberfrom .ai_workspace.tools.checkpoints.agent_checkpoint import (
lstnumber    checkpoint_plan_approved,
lstnumber    checkpoint_agent_launched,
lstnumber    checkpoint_agent_progress,
lstnumber    checkpoint_agent_complete,
lstnumber    checkpoint_agent_failed
lstnumber)
lstnumber
lstnumber# 1. User Approves Plan
lstnumbercheckpoint_plan_approved(
lstnumber    task_id="LT-4",
lstnumber    plan_summary="Lyapunov stability proofs for 7 controllers",
lstnumber    hours=46.0,
lstnumber    agents=["control_systems", "pso", "documentation"],
lstnumber    deliverables=["proofs.pdf", "benchmarks.json", "theory_guide.md"]
lstnumber)
lstnumber
lstnumber# 2. Launch Each Agent
lstnumbercheckpoint_agent_launched(
lstnumber    task_id="LT-4",
lstnumber    agent_id="agent_control_systems",
lstnumber    role="Implement Lyapunov proofs",
lstnumber    hours_allocated=18.0
lstnumber)
```

```
lstnumber
lstnumber# 3. Progress Updates (every 5-10 minutes)
lstnumbercheckpoint_agent_progress(
lstnumber    task_id="LT-4",
lstnumber    agent_id="agent_control_systems",
lstnumber    hours_completed=8.5,
lstnumber    deliverables_completed=["Lyapunov proof for classical SMC"],
lstnumber    current_phase="Implementing adaptive SMC proofs"
lstnumber)
lstnumber
lstnumber# 4. Agent Completes
lstnumbercheckpoint_agent_complete(
lstnumber    task_id="LT-4",
lstnumber    agent_id="agent_control_systems",
lstnumber    hours_completed=18.0,
lstnumber    deliverables=["lyapunov_proofs.pdf"],
lstnumber    summary="7 controllers validated, 3 new theorems proven"
lstnumber)
lstnumber
lstnumber# Or Agent Fails
lstnumbercheckpoint_agent_failed(
lstnumber    task_id="LT-4",
lstnumber    agent_id="agent_control_systems",
lstnumber    hours_completed=12.5,
lstnumber    reason="Token limit exceeded at 180K tokens",
lstnumber    recovery_recommendation="Resume from checkpoint_0012 at adaptive SMC proof"
lstnumber)
```

subsection 0.0 Recovery Commands

```
lstnumber# Standard Recovery Workflow
lstnumber/recover                    # Load project state, list incomplete tasks
lstnumber
lstnumber/resume LT-4 agent_control_systems
lstnumber                           # Resume specific agent from last checkpoint
lstnumber
lstnumber# Advanced Recovery
lstnumberpython .ai_workspace/tools/recovery/recover_project.sh
lstnumberpython .ai_workspace/tools/checkpoints/analyze_checkpoints.py --task LT-4
```

section 0 Quality Gates System

subsection 0.0 The 8 Quality Gates

0. enumi**Test Coverage**: Critical paths $\geq 95\%$, overall $\geq 85\%$
0. enumi**Critical Issues**: Zero high-severity bugs allowed
0. enumi**Memory Safety**: All controllers use weakref, no circular refs
0. enumi**Documentation**: All public APIs have docstrings + examples
0. enumi**Linting**: Ruff/Pylint score $\geq 9.0/10$
0. enumi**Type Safety**: MyPy strict mode, no `Any` types
0. enumi**Performance**: Benchmarks within 5% of baseline
0. enumi**Integration**: All 11 MCP servers operational

subsection 0.0 Pass Requirements

0.

Phase	Min Gates	Critical Gates
Development	5/8	Test Coverage
Pre-Merge	7/8	Coverage + Critical Issues
Production	8/8	All gates mandatory

subsection 0.0 Automated Validation

```
lstnumber# Run Quality Gates
lstnumberpython .ai_workspace/tools/quality/validate_quality_gates.py
lstnumber
lstnumber# Output Example
lstnumber[OK] Gate 1: Test Coverage (87% overall, 96% critical) PASS
lstnumber[OK] Gate 2: Critical Issues (0 found) PASS
lstnumber[OK] Gate 3: Memory Safety (11/11 tests pass) PASS
lstnumber[OK] Gate 4: Documentation (98% API coverage) PASS
lstnumber[WARNING] Gate 5: Linting (score 8.7/10) FAIL
lstnumber[OK] Gate 6: Type Safety (MyPy strict, 0 errors) PASS
lstnumber[OK] Gate 7: Performance (baselines within 3%) PASS
lstnumber[OK] Gate 8: MCP Integration (11/11 servers) PASS
lstnumber
lstnumber[INFO] Result: 7/8 gates pass (PRE-MERGE READY)
lstnumber[ACTION] Fix linting issues to achieve 8/8 for production
```

section 0 Case Study: Phase 3 UI Overhaul

subsection 0.0 Task Overview

- **Goal**: Achieve WCAG 2.1 Level AA accessibility across Streamlit UI
- **Scope**: 34 issues (GitHub milestones UI-001 through UI-034)
- **Duration**: 8 days (October 9-17, 2025)
- **Complexity**: 18 design tokens, 4 breakpoints, 12 color palettes

subsection 0.0 Orchestration Strategy

enumi**Week 1 (Days 1-3)**: Foundation work (Integration + Documentation agents)

0. Integration Agent: Create design system tokens
- Documentation Agent: Write accessibility guidelines

enumi**Week 2 (Days 4-6)**: Implementation (Control Systems + PSO agents)

0. Control Systems Agent: Refactor UI components to use tokens
- PSO Agent: Optimize color contrast ratios

enumi**Week 3 (Days 7-8)**: Validation (Testing + Code Beauty agents)

0. Testing Agent: Puppeteer WCAG audits
- Code Beauty Agent: Apply formatters, fix linting

subsection 0.0 Checkpoint Events

- **Checkpoint 1 (Day 2, 3h)**: Token limit during design token creation
- **Recovery 1**: Resumed from `checkpoint_0008`, lost 0 work
- **Checkpoint 2 (Day 5, 6h)**: Token limit during component refactoring
- **Recovery 2**: Resumed from `checkpoint_0015`, lost 0 work
- **Checkpoint 3 (Day 7, 2h)**: Intentional save before WCAG audits

subsection 0.0 Final Results

- **Success**: 34/34 issues resolved, WCAG AA achieved
- **Quality Gates**: 8/8 passing (production-ready)

- **Token Efficiency**: 3 recoveries, 0 work lost
- **Documentation**: 47 pages of UI guidelines generated

section 0 Multi-Account Recovery

subsection 0.0 Problem Statement

- Each Claude Code account has 200K token limit per conversation
- Large refactorings (e.g., 46-hour research roadmaps) exceed single account capacity
- Need to resume work across accounts WITHOUT losing context

subsection 0.0 Solution: Cross-Account Checkpoints

enumi**Account A**: Works until 180K tokens, hits checkpoint

0. enumi**Checkpoint System**: Saves state to `.ai_workspace/state/checkpoints/`
0. enumi**Git Commit**: Push checkpoint files to remote
0. enumi**Account B**: Pulls latest commits, runs `/recover`
0. enumi**Recovery**: Loads checkpoint, resumes work with full context

subsection 0.0 Multi-Account Workflow

```
lstnumber# Account A (reaches token limit)
lstnumbercheckpoint_agent_progress(...)   # Save progress
lstnumbergit add .ai_workspace/state/checkpoints/
lstnumbergit commit -m "chore: Save checkpoint for LT-4 agent_control_systems"
lstnumbergit push origin main
lstnumber
lstnumber# Switch to Account B
lstnumberD:\Tools\Claude\Switch-ClaudeAccount.ps1
lstnumbercd D:\Projects\main
lstnumbergit pull origin main
lstnumber
lstnumber# Account B (resume work)
lstnumber/recover                         # Load checkpoints
lstnumber/resume LT-4 agent_control_systems
```

subsection 0.0 Cross-Account Safety

0. **Conflict Prevention**: Never run same agent on multiple accounts simultaneously
- **Version Control**: All checkpoints tracked via git, merge conflicts resolved
- **State Validation**: Recovery script verifies checkpoint integrity before resume

section 0 Advanced Orchestration Patterns

subsection 0.0 Pattern 1: Sequential Pipeline

Use Case: Tasks with strict dependencies (e.g., Integration -> Documentation -> Testing)

```
lstnumber# Launch agents sequentially
lstnumberintegration_result = checkpoint_agent_launched(...)
lstnumberwait_for_completion(integration_result)
lstnumber
lstnumberdoc_result = checkpoint_agent_launched(...)
lstnumberwait_for_completion(doc_result)
lstnumber
lstnumbertest_result = checkpoint_agent_launched(...)
```

subsection 0.0 Pattern 2: Parallel Fan-Out

Use Case: Independent tasks (e.g., PSO optimization + Documentation)

```
lstnumber# Launch multiple agents in parallel
lstnumberagents = [
lstnumber    checkpoint_agent_launched("LT-4", "agent_pso", ...),
lstnumber    checkpoint_agent_launched("LT-4", "agent_doc", ...),
lstnumber    checkpoint_agent_launched("LT-4", "agent_beauty", ...)
lstnumber]
lstnumber
lstnumber# Wait for all to complete
lstnumberwait_for_all(agents)
```

subsection 0.0 Pattern 3: Hierarchical Delegation

Use Case: Sub-agent spawning (e.g., Documentation agent spawns Sphinx builder)

```
lstnumber# Parent agent launches child sub-agents
lstnumberdoc_agent = checkpoint_agent_launched("LT-4", "agent_doc", ...)
lstnumber
lstnumber# Within Documentation Agent
lstnumbersphinx_builder = spawn_sub_agent("sphinx_builder")
lstnumberapi_generator = spawn_sub_agent("api_doc_generator")
lstnumber
lstnumber# Parent waits for children
lstnumberwait_for_children([sphinx_builder, api_generator])
lstnumbercheckpoint_agent_complete("LT-4", "agent_doc", ...)
```

section 0 Monitoring & Debugging

subsection 0.0 Real-time Monitoring

```
lstnumber# Watch checkpoint updates in real-time
lstnumberwatch -n 5 'ls -lh .ai_workspace/state/checkpoints/'
lstnumber
lstnumber# Monitor agent progress
lstnumberpython .ai_workspace/tools/checkpoints/analyze_checkpoints.py --live
lstnumber
lstnumber# Output Example
lstnumber[INFO] Active agents: 3
lstnumber  - agent_control_systems (LT-4): 8.5h / 18h (47% complete)
lstnumber  - agent_pso (LT-4): 12h / 12h (100% complete)
lstnumber  - agent_doc (LT-4): 6h / 15h (40% complete)
lstnumber
lstnumber[WARNING] agent_control_systems: No checkpoint in 12 minutes (expected <10 min)
lstnumber[ACTION] Check if agent is blocked or needs manual intervention
```

subsection 0.0 Debugging Failed Recoveries

- **Symptom**: `/recover` fails to find checkpoints
- **Cause 1**: Checkpoints not committed to git
- **Fix**: `git add .ai_workspace/state/checkpoints/ && git commit`
- **Cause 2**: Checkpoint file corrupted (invalid JSON)
- **Fix**: Restore from previous commit (`git checkout HEAD~1 - .ai_workspace/state/`)
- **Cause 3**: Agent dependencies not resolved
- **Fix**: Launch dependency agents first (`/resume LT-4 agent_pso` before `agent_control_systems`)

section 0 Best Practices

subsection 0.0 Checkpoint Frequency

- **Too Frequent (<5 min)**: Overhead slows agents, git bloat

- **Too Infrequent (>15 min)**: Risk losing significant work on crash
- **Sweet Spot**: 5-10 minutes OR after completing each deliverable

subsection 0.0 Task Granularity

- **Too Large (>20h)**: Agent gets lost, hard to resume
- **Too Small (<2h)**: Orchestration overhead dominates
- **Sweet Spot**: 8-15 hours per agent task

subsection 0.0 Agent Coordination

- **DO**: Use explicit dependency tracking in checkpoints
- **DO**: Launch independent agents in parallel for speed
- **DON'T**: Assume agents can communicate directly (they can't)
- **DON'T**: Retry failed agents without fixing root cause

subsection 0.0 Git Hygiene

- Commit checkpoints immediately after creation
- Use descriptive messages: `"chore: Checkpoint LT-4 agent_pso at 8h"`
- Prune old checkpoints after task completion (keep last 3)
- Never gitignore `.ai_workspace/state/checkpoints/`

section 0 Troubleshooting

subsection 0.0 Common Issues

Symptom	Solution
Agent stuck, no progress	Check if waiting on dependency agent, launch it first
Checkpoint not found	Verify `git pull` completed, check `.ai_workspace/state/checkpoints/` exists
Recovery loads wrong task	Specify task ID: `/resume LT-4 agent_pso`
Quality gates fail	Run `validate_quality_gates.py`, fix failing gates

subsection 0.0 Emergency Recovery

```
lstnumber# If all else fails, manual recovery
lstnumbercd .ai_workspace/state/checkpoints/
lstnumberls -lt | head -5              # Find most recent checkpoint
lstnumbercat checkpoint_0023.json      # Read agent state manually
lstnumber# Resume work based on "current_phase" and "deliverables_completed"
```

Checklist: Multi-Agent Orchestration

- ☐ **Plan**: Decompose task into 3-6 agent workstreams
- ☐ **Checkpoint**: Call `checkpoint_plan_approved()` when user approves
- ☐ **Launch**: Start each agent with `checkpoint_agent_launched()`
- ☐ **Monitor**: Agent calls `checkpoint_agent_progress()` every 5-10 min
- ☐ **Complete**: Finalize with `checkpoint_agent_complete()` or `checkpoint_agent_failed()`

☐ **Validate**: Run quality gates (`validate_quality_gates.py`)

☐ **Commit**: Push checkpoints to git after each session

☐ **Recover**: Use `/recover` + `/resume` on token limit

Next Steps

- **E018**: Testing philosophy - coverage standards and validation strategies
- **E019**: Production safety - memory management and thread safety
- **E020**: MCP integration - auto-trigger strategy and server orchestration