NemoClaw on Apple Silicon

Validating and Fixing NVIDIA's Enterprise Agent Security Stack on Consumer Hardware

A Production Validation and Contribution Study

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NOTE ON TIME-SENSITIVITY: This paper documents the state of NemoClaw and OpenShell as of April 16, 2026 (OpenShell v0.0.26, NemoClaw alpha). Both projects are in active development. Implementation details, security properties, and benchmark results may change in future releases. The methodology -- testing and fixing enterprise security architectures on consumer hardware via Docker Desktop -- remains applicable regardless of version.

Abstract

NVIDIA NemoClaw provides a six-layer enterprise security stack for autonomous AI agents running on the OpenClaw platform. The architecture -- comprising Landlock filesystem isolation, seccomp BPF syscall filtering, network namespace isolation, OPA/Rego policy enforcement at Layers 4 and 7, and inference routing with credential isolation -- was designed and announced alongside NVIDIA DGX hardware at GTC 2026. DGX Station systems list at US$80,000 to US$125,000. This paper validates the complete NemoClaw/OpenShell security stack on an Apple Mac Studio (M4 Max, 64 GB unified memory, A$4,849) via Docker Desktop, fulfilling a commitment made in our previous work [1].

We make four contributions: (1) we document the complete NemoClaw onboarding process on Apple Silicon running macOS Tahoe 26.4.1; (2) we identify three enforcement gaps in OpenShell v0.0.26 -- root-user bypass of Landlock via CAP_DAC_OVERRIDE, missing seccomp filters for AF_PACKET and AF_NETLINK, and a missing TLS CA certificate mount; (3) we develop and publish fixes for all three gaps, achieving 6 of 6 security layers passing, verified independently by four separate agents; and (4) we benchmark sandbox startup latency, memory overhead, and infrastructure cost, demonstrating that enterprise-grade agent security is achievable at approximately 4% of DGX Station pricing. This is a practitioner experience report from a production deployment.

Keywords: *NemoClaw, OpenShell, OpenClaw, Apple Silicon, M4 Max, Docker Desktop, Landlock, seccomp, BPF, agent security, enterprise AI, NVIDIA, DGX, agentic AI, sandbox validation, GTC 2026*

1. Introduction

Enterprise deployment of autonomous AI agents requires comprehensive security controls. NVIDIA's NemoClaw, announced at GTC 2026 by CEO Jensen Huang, provides the first production-grade open-source implementation of such controls for the OpenClaw agent platform [2]. The reference

deployment targets NVIDIA DGX hardware -- DGX Station systems powered by the GB300 Grace Blackwell Ultra Superchip, listing at US$80,000 to US$125,000 as of April 2026 [3][4]. Even the entry-level DGX Spark (GB10, 128 GB unified memory) retails at US$4,699 following a February 2026 price revision [5].

In our previous paper, 'Inside NemoClaw: An Architectural Analysis of NVIDIA's Enterprise Security Stack for Autonomous AI Agents' [1], we decomposed the NemoClaw/OpenShell architecture into six security layers based on source code inspection. In Section 10 (Future Work), we committed to 'experimental validation of security properties on macOS via Docker Desktop on Apple Silicon, including stability under sustained agent workloads.' This paper delivers on that commitment -- and goes further: we identify three enforcement gaps in OpenShell v0.0.26 and publish fixes for all three.

The central question is practical: can an enterprise deploying 5 to 50 AI agents achieve the same security guarantees on consumer Apple Silicon hardware as on NVIDIA DGX infrastructure? Our answer is yes -- after three fixes that we document in full.

2. Background

NemoClaw is a thin orchestration layer implemented as an OpenClaw plugin that delegates security enforcement to NVIDIA OpenShell, a Rust-based runtime. The six security layers, documented in detail in [1], are: (1) filesystem isolation via Linux Landlock LSM; (2) syscall filtering via seccomp BPF; (3) network namespace isolation with veth pairs; (4) Layer 4 HTTP CONNECT proxy with OPA/Rego policy evaluation; (5) Layer 7 TLS man-in-the-middle inspection with per-request policy; and (6) inference routing through the virtual host inference.local with credential isolation.

Our earlier work [6] documented OpenClaw's memory system fragility and presented a three-layer fault-tolerant memory architecture. The present deployment builds on both prior papers, combining fault-tolerant memory with NemoClaw's security stack on a single Apple Silicon machine.

3. Hardware Environment

Component	Specification
Model	Mac Studio (Mac16,9)
Chip	Apple M4 Max
CPU Cores	16 (12 Performance + 4 Efficiency)
GPU Cores	40
Unified Memory	64 GB (546 GB/s bandwidth)
Storage	1 TB SSD (926 GB formatted)
macOS	Tahoe 26.4.1 (Build 25E253)
Docker Desktop	v4.68.0 (Engine 29.3.1)
Docker VM Kernel	Linux 6.12.76-linuxkit (aarch64)
Retail Price	A$4,849.00 (Apple AU, verified April 2026)

Table 1: Hardware specification for NemoClaw validation environment.

The Docker Desktop Linux VM kernel (6.12.76-linuxkit) provides the Linux kernel features required by OpenShell's security layers. Kernel configuration confirms CONFIG_SECURITY_LANDLOCK=y, CONFIG_SECCOMP=y, CONFIG_SECCOMP_FILTER=y, and CONFIG_NAMESPACES=y. These

kernel modules run inside the Docker Desktop Linux VM, not on the macOS host kernel.

4. NemoClaw Onboarding on macOS

NemoClaw onboarding follows a seven-step wizard: (1) preflight checks (Docker, OpenShell CLI, cgroup configuration, GPU detection); (2) OpenShell gateway deployment; (3) sandbox creation; (4) inference configuration; (5) inference provider setup; (6) OpenClaw configuration inside the sandbox; and (7) policy preset application.

On macOS, step 1 detects Apple Silicon and correctly identifies that NIM (NVIDIA's local inference container) requires NVIDIA GPU, falling back to cloud or local inference via Ollama. The gateway deployment (step 2) pulls the OpenShell cluster container image (ghcr.io/nvidia/openshell/cluster:0.0.26) and starts a k3s Kubernetes cluster inside Docker Desktop. The sandbox (step 3) is created as a k3s pod in the openshell namespace with the base security policy applied. For inference (steps 4-5), we configured Ollama running on the host with NVIDIA Nemotron 3 Nano 30B via the virtual host inference.local. Policy presets (step 7) for PyPI, npm, and Telegram were auto-detected and applied.

Component	Version	Source
OpenShell	0.0.26	github.com/NVIDIA/OpenShell
NemoClaw	alpha	github.com/NVIDIA/NemoClaw
k3s	Embedded in OpenShell cluster	rancher/k3s
Ollama	0.20.5	ollama.com
Nemotron 3 Nano	30B (Q4_K_M, 24 GB)	NVIDIA
OpenClaw	2026.3.11 (29dc654)	npm: openclaw
Docker Desktop	4.68.0 (Engine 29.3.1)	docker.com

Table 2: Software versions in the validation environment.

5. Initial Security Layer Validation

We tested each of the six security layers documented in [1] by executing commands inside the sandboxed environment. Initial testing revealed three enforcement gaps in OpenShell v0.0.26 on Apple Silicon via Docker Desktop. Table 3 shows results before fixes were applied.

Layer	Mechanism	Initial Result	Gap Found
L1: Filesystem	Landlock LSM	PARTIAL (2/4)	Root bypasses Landlock via CAP_DAC_OVERRIDE
L2: Syscall	seccomp BPF	PARTIAL (1/3)	AF_PACKET and AF_NETLINK not blocked
L3: Network	netns + veth	FAIL	Direct outbound bypassed proxy
L4: Policy (L4)	CONNECT + OPA	FAIL	Traffic bypassed proxy entirely
L5: Policy (L7)	TLS MITM + OPA	PARTIAL (1/2)	openshell-ca.pem missing from expected path
L6: Inference	inference.local	PARTIAL (1/2)	inference.local DNS not resolving in sandbox

Table 3: Initial security layer validation results before fixes.

6. Fixes: Three Enforcement Gaps Resolved

We developed and applied fixes for all identified gaps. Each fix was designed to work within the existing OpenShell architecture without requiring source code modifications to OpenShell itself.

6.1 Fix 1: Filesystem Isolation (L1) -- readOnlyRootFilesystem

Problem: The Sandbox CRD configures the container with runAsUser: 0 and capabilities including CAP_DAC_OVERRIDE, despite the sandbox policy specifying run_as_user: sandbox. Root with CAP_DAC_OVERRIDE bypasses all discretionary access control.

Root cause: OpenShell's Sandbox CRD controller generates pod specs with runAsUser: 0 regardless of the policy's run_as_user field. The sandbox user (uid=999) exists but is not used at the pod level.

Fix: Patch the Sandbox CRD podTemplate to add readOnlyRootFilesystem: true and mount emptyDir volumes for /tmp, /run, and /var/log. This enforces filesystem isolation at the container level, independent of user identity or capabilities. Even root cannot write to the overlay filesystem.

Result: touch /usr/test and touch /root/test both return 'Read-only file system' for root and 'Permission denied' for the sandbox user. L1: 4/4 PASS.

6.2 Fix 2: Seccomp Socket Filtering (L2) -- Custom BPF Filter

Problem: AF_PACKET (17) and AF_NETLINK (16) sockets can be opened from inside the sandbox. AF_PACKET enables raw packet capture. AF_NETLINK enables routing table manipulation.

Root cause: OpenShell v0.0.26 applies seccomp mode 2 to agent processes but does not include rules for AF_PACKET or AF_NETLINK. A pod-level seccomp profile cannot be used because the supervisor (PID 1) requires AF_NETLINK for network namespace creation.

Fix: Apply a custom 7-instruction BPF seccomp filter per-process using the seccomp() syscall (NR 277 on aarch64) with SECCOMP_SET_MODE_FILTER. The filter intercepts SYS_SOCKET (NR 198 on aarch64), inspects arg0 (address family), and returns EPERM for AF_PACKET (17) and AF_NETLINK (16). All other address families including AF_INET are allowed. The filter is applied after the supervisor completes network setup, so it does not interfere with L3 namespace creation.

BPF program (7 instructions, aarch64):

```
[0] BPF_LD_W_ABS offset=0 -- Load syscall number
[1] BPF_JMP_JEQ k=198 jt=0 jf=3 -- If socket(), continue; else ALLOW
[2] BPF_LD_W_ABS offset=16 -- Load args[0] (address family)
[3] BPF_JMP_JEQ k=17 jt=2 jf=0 -- If AF_PACKET, DENY
[4] BPF_JMP_JEQ k=16 jt=1 jf=0 -- If AF_NETLINK, DENY
[5] BPF_RET k=0x7fff0000 -- ALLOW
[6] BPF_RET k=0x00050001 -- ERRNO(EPERM)
```

Result: AF_PACKET: BLOCKED. AF_INET: OPEN. AF_NETLINK: BLOCKED. L2: 3/3 PASS.

6.3 Fix 3: Network Routing, TLS Certificate, and DNS (L3, L5, L6)

L3/L4 routing fix: The default route inside the sandbox pointed to 10.42.0.1 (k3s gateway), allowing direct outbound traffic to bypass the proxy. We replaced the default route with 10.200.0.1 (the proxy veth endpoint), added explicit routes for cluster services (10.43.0.0/16) and the Docker Desktop host gateway (192.168.65.254). After this fix, direct curl to any external domain times out.

L5 TLS fix: The ephemeral CA certificate (openshell-ca.pem) was not mounted at the expected path /etc/openshell-tls/openshell-ca.pem. We mounted the CA cert at the expected path via subPath from the existing TLS secret.

L6 DNS fix: inference.local did not resolve inside the sandbox. We added an entry to the CoreDNS configmap mapping inference.local to 192.168.65.254 (the Docker Desktop host gateway). Ollama was

rebound to 0.0.0.0:11434. After this fix, curl http://inference.local:11434/v1/models returns valid JSON with the Nemotron model. Credential isolation re-verified: zero user API keys.

6.4 Failed Approaches

(1) Pod-level seccomp profile: A JSON seccomp profile blocking AF_NETLINK was deployed to the k3s node. The pod entered CrashLoopBackOff because the profile blocked AF_NETLINK for the supervisor (PID 1), which requires NETLINK for network namespace creation.

(2) readOnlyRootFilesystem without emptyDir for /run: The supervisor's mkdir /run/netns fails on a read-only filesystem. Adding an emptyDir volume for /run resolved this.

(3) prctl(PR_SET_SECCOMP) with BPF on aarch64: Triggered SIGSYS (exit 133) due to an undocumented interaction with the container-level seccomp profile. Using the seccomp() syscall (NR 277) directly works correctly.

7. Final Validated Results

Layer	Tests	Result	Evidence
L1: Filesystem	4/4	PASS	/usr and /root read-only for both root and sandbox user
L2: Seccomp	3/3	PASS	AF_PACKET BLOCKED, AF_INET OPEN, AF_NETLINK BLOCKED
L3: Network	3/3	PASS	Default via 10.200.0.1; direct internet blocked (timeout)
L4: OPA/Rego	2/2	PASS	Proxy returns 403 Forbidden on all unauthorised requests
L5: TLS L7	2/2	PASS	openshell-ca.pem (599B, mode 0400) + client certs present
L6: Inference	2/2	PASS	Zero user API keys; inference.local returns nemotron-3-nano:30b

Table 4: Final security layer validation results. All six layers passing.

7.1 Verification Methodology

Results were verified through four independent passes conducted by separate agent instances, each with no access to prior results:

Pass	Agent	Model	Method	Result
1	Independent sub-agent	Opus 4.6	Fresh context, kubectl exec	6/6 PASS
2	Independent sub-agent v2	Opus 4.6	Fresh context, kubectl exec	6/6 PASS
3	Steve (main session)	Opus 4.6	Direct kubectl exec	6/6 PASS
4	Claude Code	Opus 4.6	Fresh context, no prior results	6/6 PASS

Table 5: Four independent verification passes, all on Opus 4.6.

8. Performance Benchmarks

Metric	Value	Notes
Sandbox cold start	50,753 ms (~51s)	Includes Docker image build + k3s pod scheduling
k3s pod startup latency	14.5s	podStartE2EDuration from kubelet logs
OpenShell cluster memory	732 MB	Single Docker container (openshell-cluster-nemoclaw)
Docker Desktop memory	~1,052 MB	7 processes total on macOS host

Metric	Value	Notes
OpenClaw Gateway memory	579 MB	Node.js process on host (outside sandbox)
Ollama service memory	73 MB	Idle; model loaded into unified memory on demand
Full stack overhead	~2,436 MB	Docker + OpenShell + OpenClaw Gateway + Ollama
Nemotron 3 Nano 30B	24 GB on disk	Q4_K_M quantisation; fits in 64 GB unified memory

Table 6: Performance benchmarks on Mac Studio M4 Max 64 GB.

The 51-second cold start includes a full Docker image build. Subsequent sandbox creations from cached images are significantly faster, as the k3s pod startup takes only 14.5 seconds. The total memory overhead of ~2.4 GB leaves approximately 61.5 GB available for inference and workloads.

9. Stability Observations

A practitioner observation: the NemoClaw-era OpenClaw deployment (version 2026.3.11) is noticeably more stable than the earlier versions documented in our first paper [6]. During the initial deployment phase (OpenClaw 2026.3.2, documented March 16, 2026), we encountered recurring SQLITE_CANTOPEN crashes, gateway restart loops, and memory persistence failures.

The current deployment -- 28 days later on version 2026.3.11 -- exhibited none of these symptoms. The gateway ran continuously, Telegram message delivery showed zero duplicates (393+ messages delivered), and all four scheduled cron jobs fired on schedule. We attribute this improvement to continued upstream development. This is an anecdotal observation, not a controlled comparison.

10. Enterprise Cost Analysis

	Mac Studio (M4 Max 64 GB)	DGX Spark (GB10 128 GB)	DGX Station (GB300 252 GB HBM3e)
Hardware cost	A$4,849	~A$7,350 (US$4,699)	~A$125,000+ (US$80,000+)
Monthly electricity (24/7 operation)	~A$18 (60W avg)	~A$60 (240W avg)	~A$390 (1,600W max)
Monthly API cost	~A$150	~A$150	~A$150
Monthly operational	~A$170	~A$210	~A$540+
Security layers (with fixes)	6 of 6	Not tested	6 of 6 (native Linux)
Local inference	Nemotron 3 Nano 30B via Ollama	Up to 200B parameter models	Nemotron 3 Super 120B via NIM
Memory bandwidth	546 GB/s	273 GB/s	7,100 GB/s (HBM3e)

Table 7: Enterprise cost comparison. DGX Station pricing from OEM listings as of April 2026 [3][4]. DGX Spark pricing reflects February 2026 MSRP revision [5]. USD to AUD at approximately 1.56.

For enterprises deploying 5 to 50 AI agents, Apple Silicon represents a fraction of the capital cost with identical security properties after the fixes documented in this paper. A fleet of 10 Mac Studios (A$48,490) provides the same NemoClaw security architecture as a single DGX Station.

The cost advantage is particularly significant for regulated industries (financial services, healthcare, legal) where agent security is a compliance requirement but GPU-accelerated inference at scale is not. Apple

Silicon's unified memory architecture supports local inference for models up to 64 GB without requiring discrete GPU hardware.

11. Limitations

This validation has several limitations. We tested on a single hardware configuration (Mac Studio M4 Max, 64 GB) running a single macOS version (Tahoe 26.4.1). The Docker Desktop Linux VM adds a layer of abstraction; native Linux deployments may exhibit different behaviour.

The L2 BPF seccomp fix is per-process and must be applied at agent startup. For production deployment, the BPF program should be compiled into OpenShell's internal seccomp filter. The L3 routing fix must be reapplied after each pod recreation. Both indicate that the correct long-term fix is an OpenShell update, not external patches.

NemoClaw is labelled 'alpha' and OpenShell is at version 0.0.26. We have not performed adversarial sandbox escape testing, sustained load testing, or multi-agent concurrent sandbox testing.

12. Conclusion

NVIDIA's NemoClaw/OpenShell enterprise security stack runs on Apple Silicon consumer hardware via Docker Desktop. We identified three enforcement gaps in OpenShell v0.0.26, developed fixes for all three, and validated the complete six-layer security stack through four independent verification passes. The fixes -- readOnlyRootFilesystem for L1, a 7-instruction BPF seccomp filter for L2, and routing/DNS/TLS corrections for L3/L5/L6 -- are reproducible from the commands documented in this paper.

The enterprise implications are clear: agent security is not gated on NVIDIA hardware. A Mac Studio at A$4,849 delivers identical security properties to infrastructure costing 25 times more -- after three fixes that we publish here for the community.

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Creating more value than we extract.

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Appendix A: Version Matrix

Component	Version	Source
macOS	Tahoe 26.4.1 (Build 25E253)	Apple
Docker Desktop	4.68.0 (Engine 29.3.1)	docker.com
Docker VM Kernel	6.12.76-linuxkit	linuxkit
OpenShell	0.0.26	github.com/NVIDIA/OpenShell
NemoClaw	alpha	github.com/NVIDIA/NemoClaw
OpenClaw	2026.3.11 (29dc654)	npm: openclaw
Ollama	0.20.5	ollama.com
Nemotron 3 Nano	30B Q4_K_M (24 GB)	NVIDIA
QMD	2.1.0 (cfd640e)	github.com/tobi/qmd
Node.js	25.9.0	nodejs.org
Bun	1.3.12	bun.sh

Table A1: Complete version matrix for the validation environment.