Scientific AI and the Future of OME-Zarr

Building Intelligent Bioimage Analysis Workflows

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EMBL Advanced Methods in Bioimage Analysis

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🌐 HTML slides | 📄 PDF slides | 📁 GitHub repository

Today's Journey

50 minutes + 10 minutes Q&A

1. **Extended introduction to ngff-zarr** (15 min)
    - Converting bioimages to OME-Zarr
2. **Introduction to MCP Servers** (15 min)
    - Add the ngff-zarr MCP server to agentic AI tools
3. **The ngff-zarr MCP Server in Action** (15 min)
    - AI-powered conversions and batch processing
4. **fideus labs introduction** (5 min)

Part 1: Introduction to ngff-zarr

Next-Generation Scientific Imaging

What is OME-Zarr?

- **Cloud-native** bioimaging file format from the Open Microscopy Environment (OME)
- Built on **Zarr** - chunked, compressed array storage
- **Multiscale** pyramidal data structure
- **Interoperable** across platforms and tools
- **FAIR** data principles: Findable, Accessible, Interoperable, Reusable

Why OME-Zarr Matters

Traditional Problems:

- 🏭 Vendor-specific proprietary formats
- 📦 Monolithic files difficult to stream
- ☁️ Limited cloud compatibility
- 🐢 Poor scalability for large datasets

OME-Zarr Solutions:

- 📖 Open specification
- 🧩 Chunked data access
- 🌐 Cloud-optimized storage
- ⚡ Parallel processing friendly

What is ngff-zarr?

- ngff-zarr is an *lean and kind* open-source toolkit for working with OME-Zarr, the next-generation file format for scientific imaging.
- Provides **command-line**, **Python**, **TypeScript**, and **AI** interfaces for converting, validating, optimizing, and analyzing bioimaging data.
- Developed by the OME-Zarr and ITK communities for **interoperability** and **performance**.
- Supports a wide range of scientific image formats and workflows.

ngff-zarr

What can ngff-zarr do for you?

- 🔄 **Convert** your **scientific images** (NRRD, TIFF, HDF5, and more) to OME-Zarr for scalable, cloud-ready storage.
- ✅ **Validate** OME-Zarr datasets to ensure compliance and **interoperability**.
- 🛠️ **Optimize** chunking and compression for **efficient access** and **storage**.
- 🤖 **Integrate** with **AI** and **analysis tools** via the **Model Context Protocol (MCP)**.
- 🚀 **Automate** batch **processing** and reproducible workflows for large-scale projects.

🛠️ Hands-On: Converting bioimages to OME-Zarr

Pixi

next-gen package manager for reproducible development setups

📦 Prerequisites: Pixi reproducible software environment

What is Pixi?

Pixi is a **fast, modern,** and **reproducible package** and **environment manager** built on the **conda ecosystem**. It provides:

- 🚀 **Easy, reproducible environments** for **any language**
- 🛠️ **Task runner** for project automation
- 🔒 **Isolation** and **cross-platform** support (Linux, macOS, Windows)
- 📦 **Simple dependency management** with a single file (`pixi.toml` or `pyproject.toml`)

⬇️ How to install Pixi

On Linux/macOS:

```
wget -qO- https://pixi.sh/install.sh | sh
```

On Windows (PowerShell):

```
powershell -ExecutionPolicy ByPass -c "irm -useb https://pixi.sh/install.ps1 | iex"
```

After installation, add `~/.pixi/bin` (Linux/macOS) or `%USERPROFILE%\.pixi\bin` (Windows) to your PATH if not done automatically.

🚀 How to run Pixi tasks

Pixi lets you define and run project tasks in your `pixi.toml` or `pyproject.toml`.

To run a task (e.g., `start`):

```
pixi run start
```

You can define custom tasks (like `test`, `lint`, etc.) and run them the same way:

```
pixi run test
pixi run lint
```

Pixi ensures all dependencies and the environment are set up before running your task.

🐚 Interactive shell with `pixi shell`

Enter an interactive shell with your project environment activated:

```
pixi shell
```

What happens:

- 🔧 **Environment activated** - all dependencies available
- 🎯 **Direct command execution** - no need for `pixi run` prefix
- 🚪 **Easy exit** - just type `exit` when done

👩‍💻 Exercise 1: Convert the sample NRRD image to OME-Zarr

```
pixi run convert
```

What Just Happened?

- 🔍 **Automatic multiscale generation** - without aliasing artifacts
- 🧩 **Intelligent chunking** - optimized for access patterns
- 📊 **Metadata preservation** - spatial information maintained
- 🗜️ **Compression applied** - reduced file size
- ☁️ **Cloud-ready format** - object-store optimized, can be served via HTTP

👩‍💻 Exercise 2: Convert the sample NRRD image to OME-Zarr version 0.5

```
pixi run convert-ome-zarr-0.5
```

```
# Count the number of files created
find carp.ome.zarr -type f | wc -l
```

👩‍💻 Exercise 3: Convert the sample NRRD image to OME-Zarr with sharding

```
pixi run convert-sharding
```

```
# Count the number of files created
find carp.ome.zarr -type f | wc -l
```

What Just Happened? ✨ New in OME-Zarr 0.5

- 🪣 **Sharding enabled** - multiple chunks stored in single files
- 📦 **Optimized storage** - fewer small files, better filesystem performance

What is Sharding?

Sharding combines multiple small chunks into larger "shard" files, dramatically reducing the number files needed to store data while maintaining random access capabilities.

Part 2: Introduction to MCP Servers

Connecting AI to Your Data

🧠 Understanding Large Language Model (LLM) Context

What is Model Context?

- 📝 **Information** the AI model can "see" and reason about
- 🧮 **Limited capacity** - typically measured in tokens (words/symbols)
- ⏱️ **Temporary memory** - context is conversation-specific
- 🎯 **Scope of knowledge** for making informed decisions

🧠 Understanding Large Language Model (LLM) Context

Why Context Matters:

- 🔍 **Better understanding** - more relevant, accurate responses
- 🎛️ **Tool selection** - AI chooses appropriate tools for the task
- 🔗 **Data integration** - combines multiple information sources
- 🚀 **Workflow automation** - maintains state across complex operations

The Challenge: *How do we give AI access to your scientific data and tools?*

What is the Model Context Protocol (MCP)?

Universal standard for connecting AI assistants to external data and tools

Key Components:

- 🤖 **MCP Client** - integrated in AI applications
- 🖥️ **MCP Server** - exposes specific capabilities
- 🔗 **Transport Layer** - JSON-RPC 2.0 communication
- 🔧 **Standardized Interface** - tools, resources, prompts

MCP Architecture

```
AI Application (Qodo, Claude, etc.)
    ↕ JSON-RPC 2.0
MCP Client
    ↕ STDIO/HTTP
MCP Server (ngff-zarr)
    ↕
Scientific Data & Tools
```

Benefits:

- Single protocol for all integrations
- Bidirectional communication
- Context-aware AI interactions

Why MCP for Scientific Computing?

Before MCP:

- 🔧 Custom integrations for each tool
- 🚫 Limited AI access to scientific data
- ✋ Manual, error-prone workflows

With MCP:

- 💬 **Natural language** interface to scientific tools
- 🤖 **Automated** data processing pipelines
- 🧠 **AI-driven** optimization and analysis
- 🔄 **Reproducible** computational workflows

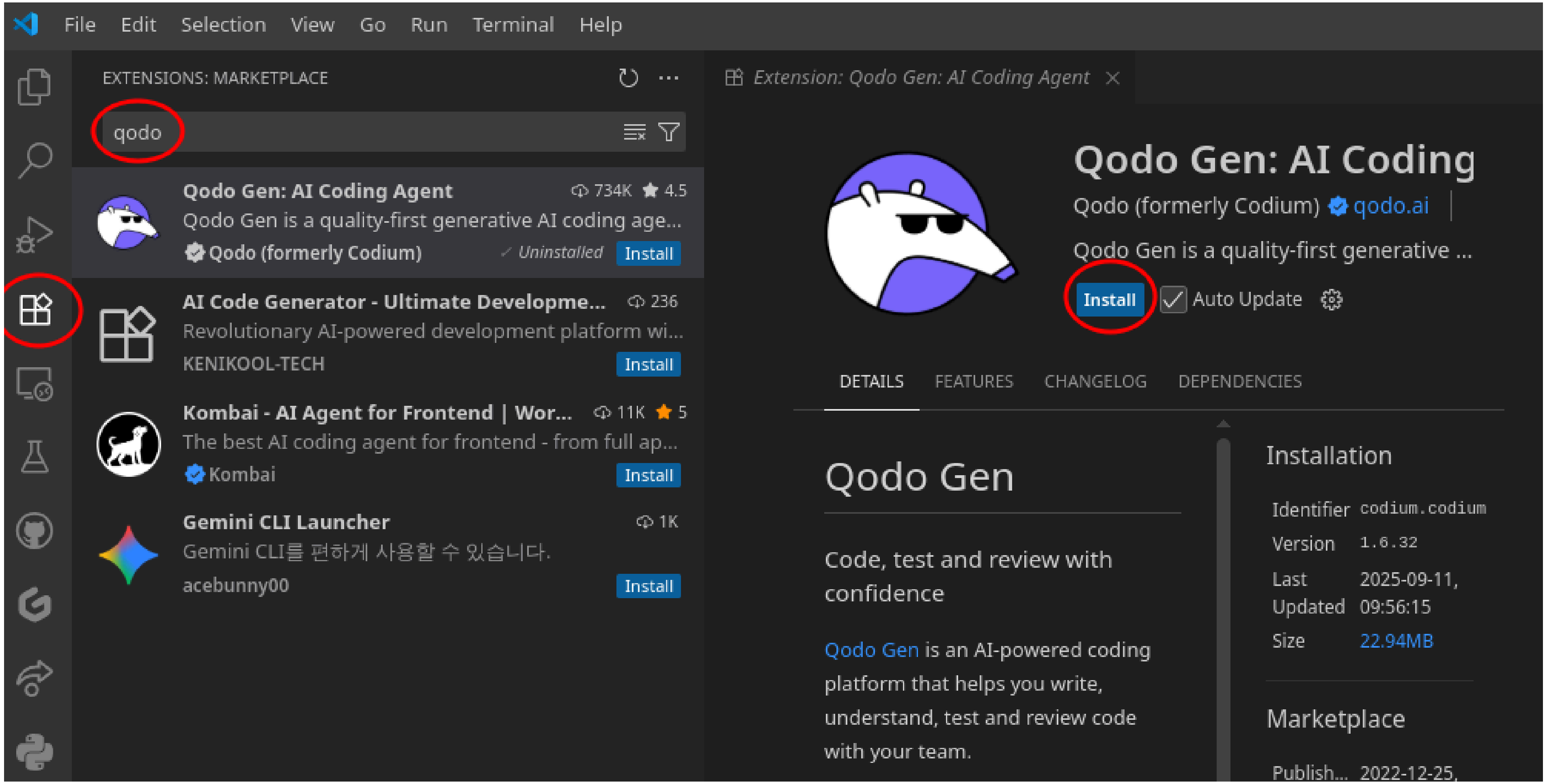
🛠️ Hands-On: Configure Qodo with the ngff-zarr MCP

Install uv, if not already installed

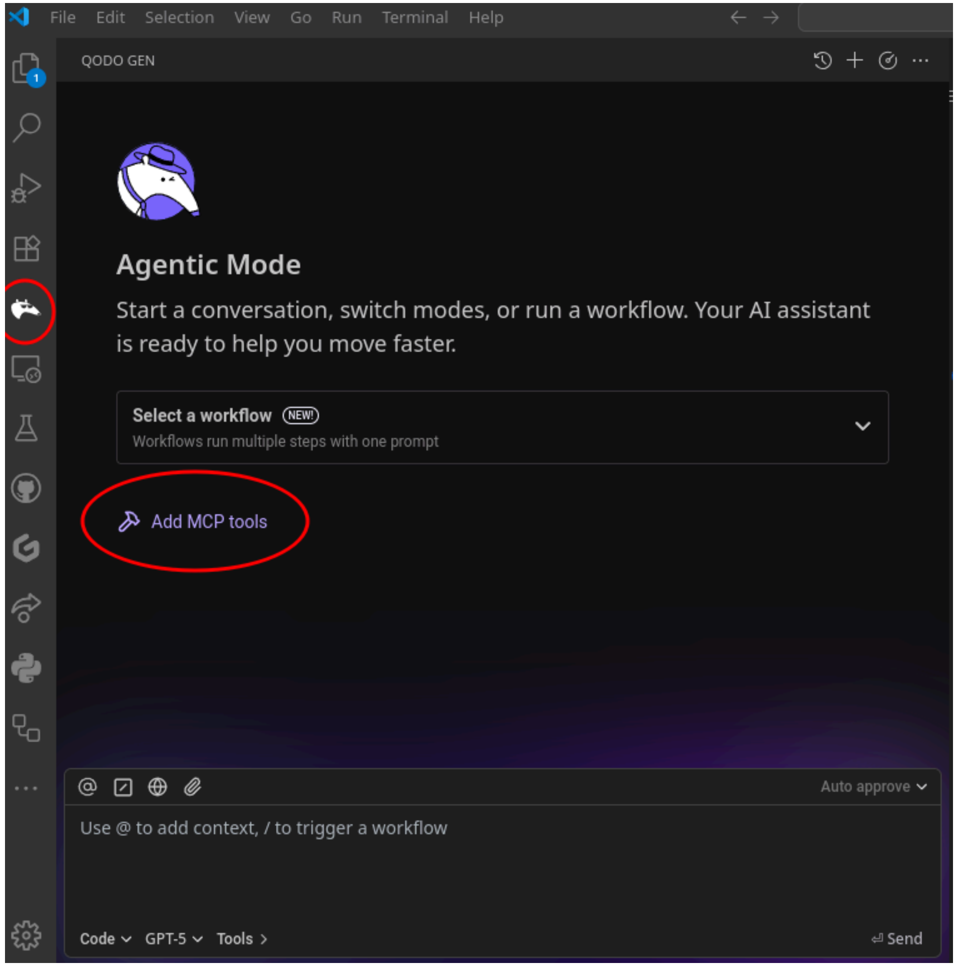
```
pixi global install uv
```

`uvx`, which comes with `uv`, will be used to install the `ngff-zarr-mcp` command-line tool and its dependencies, and run the MCP server.

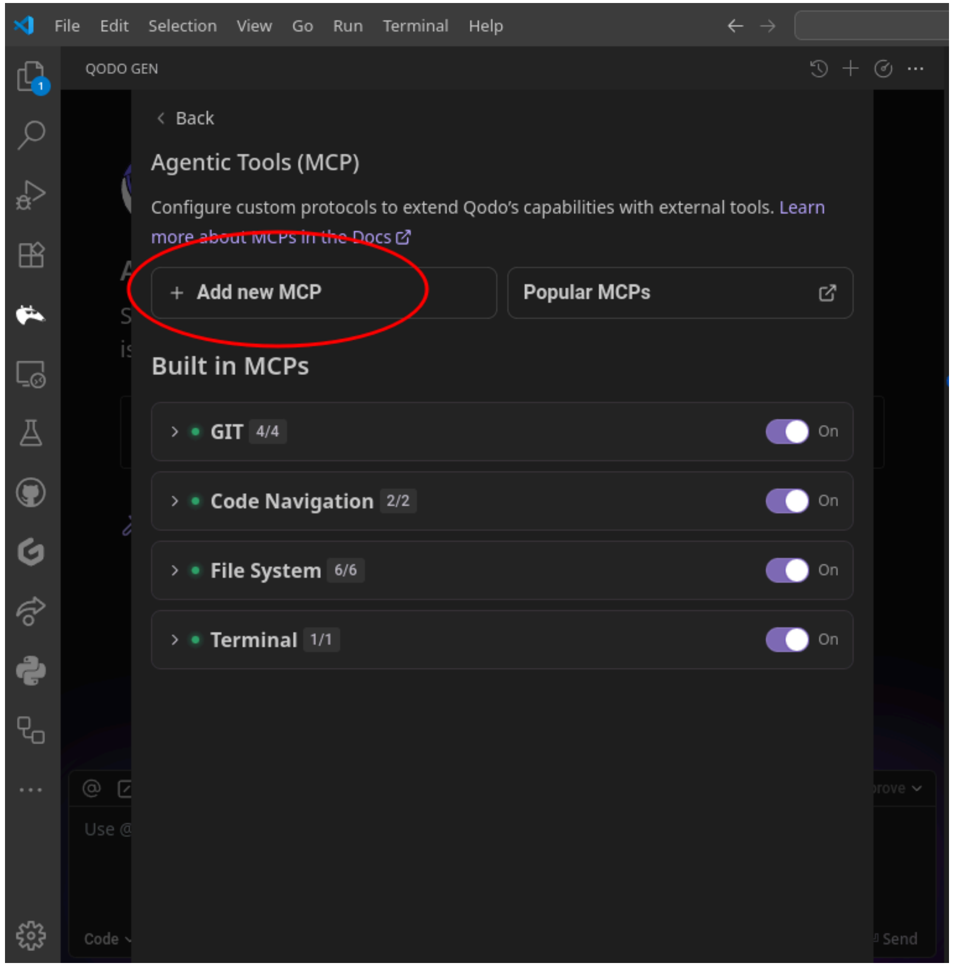
Install Qodo Extension in VS Code



Add Qodo MCP Tools

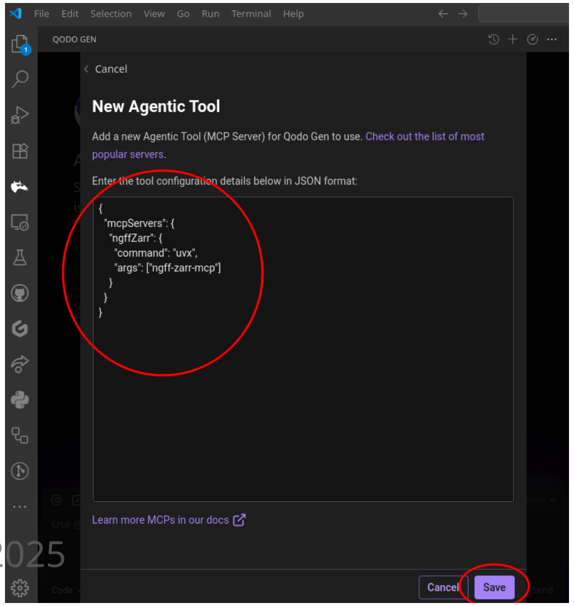


Add new MCP

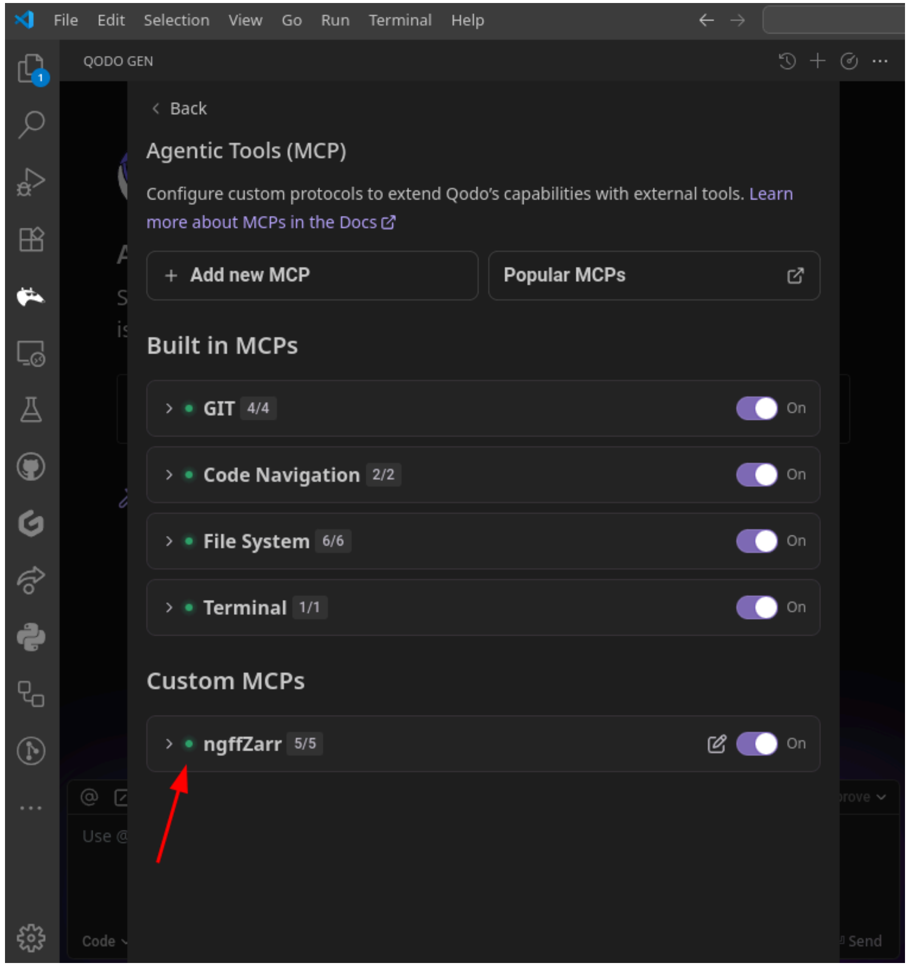

File Edit Selection View Go Run Terminal Help
QODO GEN
Back
Agentic Tools (MCP)
Configure custom protocols to extend Qodo's capabilities with external tools. Learn more about MCPs in the Docs
+ Add new MCP
Popular MCPs
Built in MCPs
GIT 4/4
On
Code Navigation 2/2
On
File System 6/6
On
Terminal 1/1
On
Use @
Code
Send

Add the ngff-zarr MCP server config

```json
{
  "mcpServers": {
    "ngffZarr": {
      "command": "uvx",
      "args": ["ngff-zarr-mcp"]
    }
  }
}
```



Watch the ngff-zarr MCP server start



Part 3: The ngff-zarr MCP Server

AI-Powered Scientific Image Processing

ngff-zarr MCP Server Capabilities

Core Functions:

- 🔄 Convert scientific formats to OME-Zarr
- 🔍 Inspect and validate OME-Zarr stores
- 🛠️ Optimize compression and chunking
- 📝 Generate processing scripts
- 📦 Batch operation planning

AI Integration:

- 💬 Natural language commands
- 🎯 Intelligent parameter selection
- 🤖 Automated workflow generation

🛠️ Hands-On: AI-Powered Conversion

💬 Convert a bioimage with AI assistance

Put the Qodo Anteater to work!

In Qodo chat:

```
Convert the vs_male.nrrd file to OME-Zarr format and
find the optimal compression codec for this type of data.
```

✨ **Watch the AI agent**:

1. 🔍 Analyze the input file
2. 🎯 Select appropriate parameters
3. ⚙️ Execute the conversion
4. 📊 Report optimization results

💬 Examine OME-Zarr contents

Ask the AI to explore:

```
Examine the contents of carp.ome.zarr and tell me
about its structure, dimensions, and metadata
```

✨ **The AI agent will**:

- 🔍 Inspect multiscale levels
- 📏 Report spatial metadata
- 🧩 Analyze chunk structure
- ✨ Suggest next steps

💬 Generate batch script

Scale up with AI automation:

```
I have a folder of 50 similar NRRD files.
Generate a Python script to batch convert them all
to OME-Zarr with the same optimal settings
```

✨ **The AI agent creates:**

- 🐍 Complete Python script
- ⚠️ Error handling
- 📈 Progress reporting
- 🎯 Optimized parameters from previous analysis

The Future of Scientific AI

Today's Demo Shows:

- 💬 **Conversational** scientific computing
- 🤖 **Automated** optimization
- 🔄 **Reproducible** workflows
- ✨ **Accessible** advanced techniques

Tomorrow's Possibilities:

- 🧬 Multi-modal analysis pipelines
- 🧠 Intelligent experiment design
- 🛡️ Automated quality control
- 🌐 Cross-platform integration

fideus labs

Fostering trust 🤝 and advancing understanding 🧠 from scientific and biomedical images 🔬

About fideus labs

Specialties:

- **Biomedical Imaging** - ITK core development
- **Scientific Visualization** - advanced rendering
- **Open science** - pioneering decentralized science
- **AI Integration** - intelligent workflows

Open Source Leadership:

- ITK (Insight Toolkit) core team
- OME-Zarr ecosystem contributor
- Curate ngff-zarr development

Our Approach

Research Partnership:

- Government laboratories
- Academic institutions
- Industry leaders
- Open source communities

Connect With Us

fideus labs services:

- Custom imaging solutions
- Scientific software development
- Training and consultation

Connect

- Subscribe to our newsletter
- Email us: info@fideus.io
- Follow our GitHub

We are hiring! Send us your CV and GitHub profile.

Key Takeaways

- ✅ **OME-Zarr** - Future of scientific imaging formats
- ✅ **MCP Servers** - Bridge AI and scientific tools
- ✅ **Natural Language** - New interface for scientific computing
- ✅ **Accessible Research** - Cloud-native, collaborative science

Questions & Discussion

What we covered:

- OME-Zarr fundamentals and conversion
- MCP architecture and benefits
- AI-powered scientific workflows

Let's discuss:

- Your specific use cases
- Integration challenges
- Future possibilities
- Next steps for implementation