Humanoid Robots 2025

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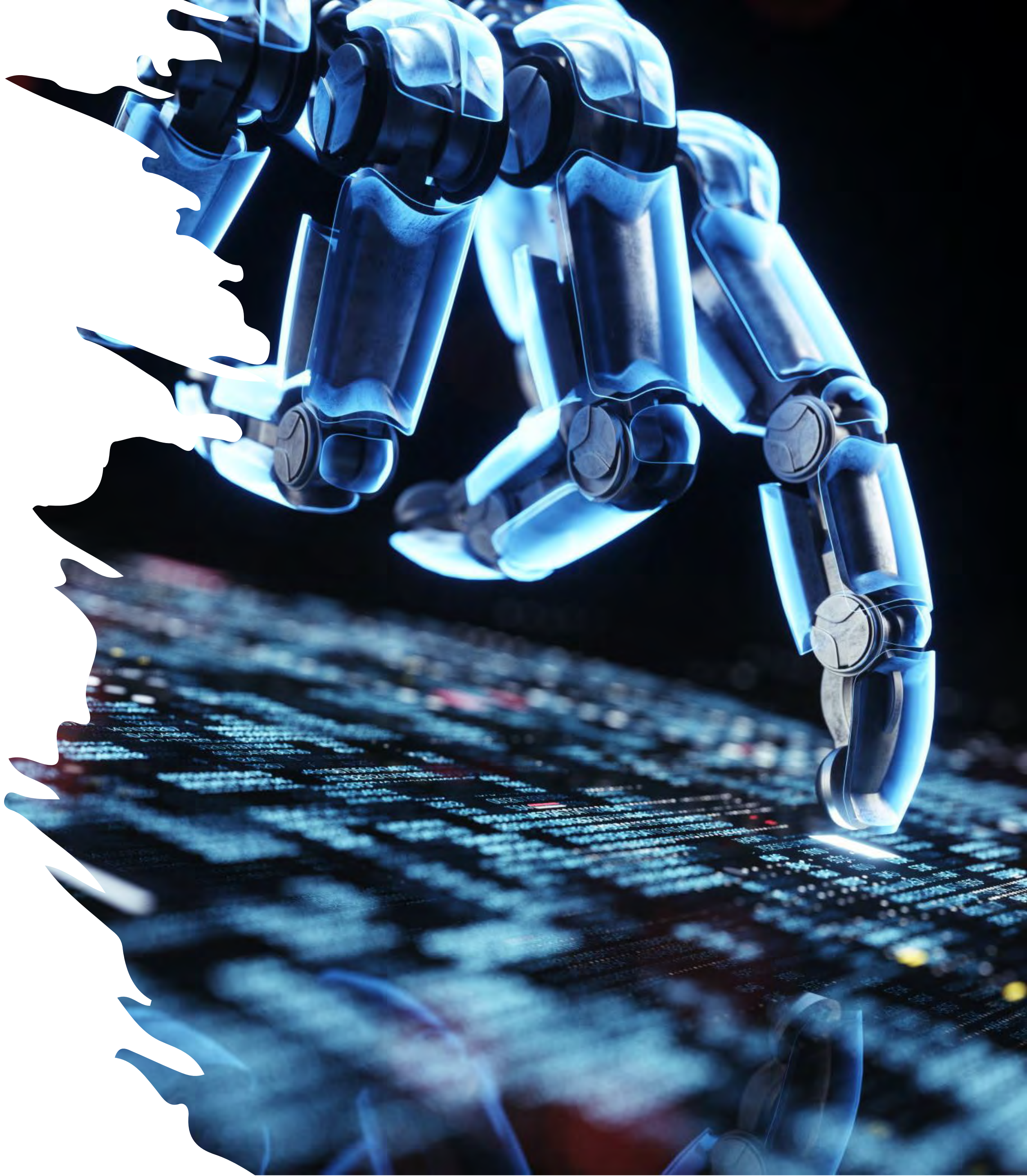
Company	Model	Height	Weight*	Speed*	Strength*
x1	Gamma	5'6" / 167cm	66 lb / 30 kg	1.1–1.5 m/s (est.)	44+ lb / 20+ kg
Figure	02	5'6" / 168cm	154 lb / 70 kg	1.2 m/s	44 lb / 20 kg
Sanctuary AI	Phoenix	5'7" / 170cm	155 lb / 70 kg	1.34 m/s	55 lb / 25 kg
Aptronik	Apollo	5'8" / 167cm	160 lb / 72.5 kg	1.52 m/s	55 lb / 25 kg
Agility	Digit	5'9" / 175cm	143 lb / 65 kg	1.5 m/s	35 lb / 16 kg
Boston Dynamics	Atlas	5'9" / 175cm	165 lb / 75 kg	1.5 m/s	Not specified
Unitree	H1	5'11" / 180cm	104 lb / 47 kg	3.3 m/s	Not specified
Tesla	Optimus	5'11" / 180cm	103 lb / 47 kg	1.5 m/s	45 lb / 20 kg

*Reported

Humanoid Robots – Key Takeaways

- Humanoid robots seen as emerging tools for labor shortages & aging workforce
- Industry shifting from research prototypes to practical deployments
- Safety, compliance, and human-robot collaboration are central concerns
- Flexible automation needed for small-batch and customized production
- Simulation, digital twins, and AI training key to scaling robotics
- Physical AI enables real-time perception, reasoning, and adaptability
- Ecosystem partnerships critical for hardware, software, and standards
- Progress in mobility, dexterity, and manipulation drives adoption
- Autonomous operation with context awareness enhances productivity
- Challenges remain in cost, reliability, and integration into workflows
- Growing interest in humanoids for logistics, healthcare, and service sectors
- Focus on robots augmenting human capability, not replacing workers



Hospital Deliveries – Diligent Robotics

Diligent Robotics & Moxi: Key Takeaways

- **Mission:** Free clinicians from repetitive logistics tasks so they can focus on patient care.
- **Product:** *Moxi* – a hospital delivery robot (supplies, meds, samples, equipment).

Approach to deployment:

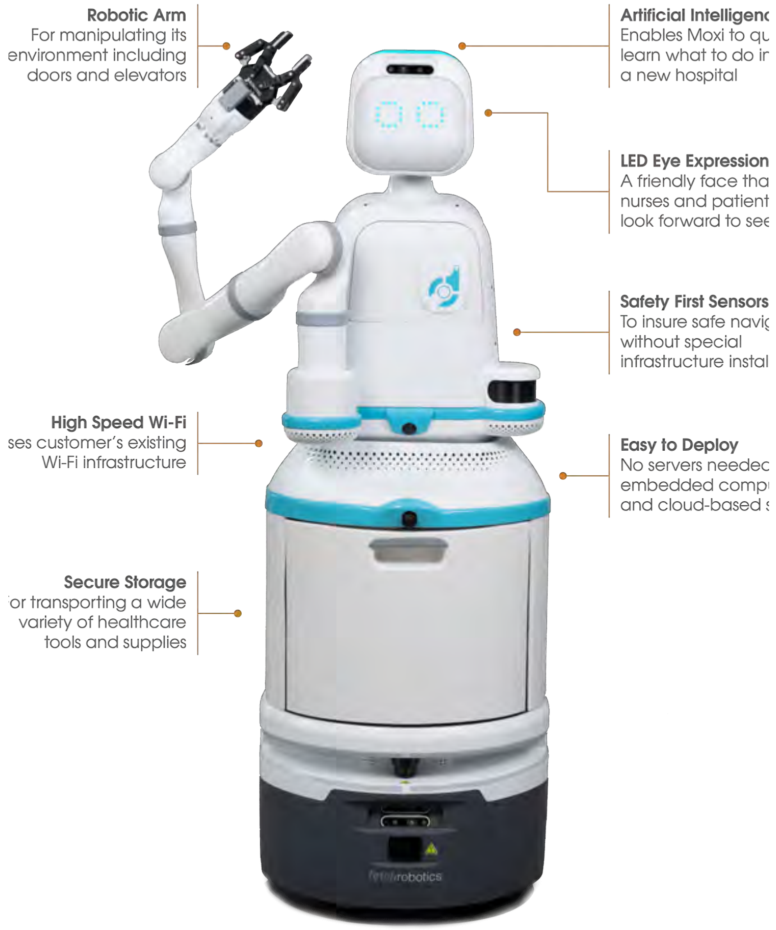
- Deploy early with *minimum critical* tasks THEN scale.
- Use real-world data + human-robot interaction insights to iterate.
- Build a **data flywheel**: deployments → data → improved models → new capabilities.

Impact:

- Hundreds of thousands of clinician hours saved.
- Active fleet across 25–30 hospitals, collecting 400+ TB of multimodal data.

Growth Path (4 Stages):

- Discover use case
- Scale single use case & collect data
- Improve autonomy & unit economics
- Enterprise-scale deployment



Space Race in Humanoids - Apptronik

- Apptronik began in 2016, **rooted in DARPA Robotics Challenge experience**.
- Built ~15 prototype robots before commercial focus; now ~300+ employees and strong AI partnerships (notably Google DeepMind).

Early skepticism: humanoids “too expensive, complex, impractical.”

- Shift today: consensus they *will* exist — debate is about **timing** and **form factor** (legs vs wheels, humanoid vs modular).
- Pragmatic stance: humanoids are the end goal, but wheels will dominate in near-term industrial/healthcare deployments.

Key Challenges & Lessons

- Wheels simpler, faster to market, good for flat environments.
- Legs enable full-body control, small footprints, and access to constrained spaces — but far harder to engineer.
- Barrier-guarded → cooperative (stops near humans) → collaborative (full safe operation around people).
- True collaborative safety is the “holy grail,” requiring robust sensing + safe AI control.

Hands & manipulation: debate between dexterous human-like hands (versatile, transferable from human data) vs simpler grippers (cheaper, more robust).

Partnerships & Strategy - Shift from full-stack independence toward **deep partnerships** (e.g., DeepMind) for AI integration.

Commercialization & Scale

- Current stage: pilots in factories (e.g., with Mercedes) exploring real tasks.
- 2027+ projected inflection: broader commercialization, scaling into tens of thousands of units.
- MVP = robots that deliver *customer ROI* (task performance, uptime, MTBF) even if not yet profitable on unit economics.

Focus for Next 6–12 Months

- Hardware: reduce cost & complexity, refine actuators, improve hand robustness.
- Software: better task performance, model integration, fleet management.
- 2026 framed as make-or-break year — promises must convert into reliable, scaled deployments.

Lab to Life – Agility Robotics

Industry Landscape

- **Robotics is in a hype cycle** - flashy demo videos abound, but real value comes from reliable, scalable deployments.
- Bold projections (e.g., Morgan Stanley's 1B humanoids by 2050) highlight potential, customer value is the true driver.

Key Learnings from Deployment

Role of General-Purpose Humanoids

- Humanoids cannot replace all automation rather should complement it.
- Best suited for **mobile manipulation tasks** (moving + handling payloads, bridging existing automation).

Compound Skill Growth

- Skills must build from **simple → complex**.
- Example: tote handling → box handling → palletizing.
- Reliability at each step strengthens future capabilities.

Customer-Centered Success

- Customers set KPIs: **ROI, reliability, safety, data security**.
- Sometimes **reliability > speed** (e.g., handling expensive machine parts safely).
- Integration with existing automation is essential.

AI as a Concrete Tool

- AI isn't a magic "black box" — it's a measurable engineering tool.
- Applied incrementally: reinforcement learning, perception models, control stability.
- Benchmarked against clear KPIs before rollout.

- **Safety is THE Gating Factor for Adoption**
- **Safety mechanisms MUST developed and adopted BEFORE mass deployments**
- **Stages of safety maturity**:
  - **Confinement** – external barriers.
  - **Cooperative** – onboard sensing; share space, not simultaneous tasks.
  - **Collaborative** – humans & robots working together in real-time.

Takeaway

- Start in **structured industrial/logistics environments**.
- Grow skillsets step by step.
- Prioritize **safety, reliability, and customer-driven KPIs**.
- Use AI and data as rigorously tested tools, not hype.

Agility Robotics positions its bipedal robot, Digit, as a multipurpose, human-centric worker for logistics, manufacturing, and warehouse automation.

Advanced Bionic Hands – PSYONIC

<u>Commercialization</u>

- ~9.5 generational iterations, becoming more anthropomorphic and sensor-rich. Real-world outcomes include veterans doing pushups, users feeding grandchildren, catching/throwing baseballs, and other daily & athletic activities.

<u>Key tech features:</u>

- Fast closing speed (~0.2s) and compliant, anthropomorphic finger behavior for natural grasping.
- Touch feedback / proprioception via force sensors and vibrotactile feedback so users can feel contact and modulate grip (enables delicate tasks like handling an egg).
- Modular/repairable design (replaceable fingers in minutes).
- Robotics crossover: **Same hands are used on humanoid robots** (NASA Valkyrie, other humanoids) and robot arms for assembly, cooking tasks (pancake flipping), Rubik’s cube, etc. Teleoperation and robot control use cases highlighted.
- Neural interfaces & implants: Work toward direct neural control (microwire electrodes, titanium bone attachment) — referenced collaborations, a 60 Minutes case where brain implants controlled a robotic arm and provided touch sensations.
- Impact stories: Several human success stories — e.g., baseball player regaining pitching/ hitting, users performing previously impossible tasks, and emotional reconnections (feeling a part of themselves restored).

<u>Future directions:</u>

- Expanding to wrists, elbows, knees, ankles and tighter human ↔ robot data transfer.
- Possibility of transfer learning from human data to robot control.
- Clinical trials planned for neural implants to enable individual-finger control (piano/keyboard example).
- They’re raising investment; interested parties invited to talk.

Your Blueprint for Developing Your Humanoid Go-To-Market Strategy - Hai Robotics

What's Special About Humanoids

- Task flexibility: The same unit can unload trailers, pick items, and reload in one day — unlike other warehouse robots.
- Minimal IT integration & reconfiguration compared to automation systems.
- High potential customer value if applied correctly.
- *HOWEVER* - variability in warehouse operations is both strength and weakness — different contexts mean "new use cases" that humanoids must adapt to.

Key Challenges

- **No clear use case definition yet** for humanoids in warehouses.
- **Safety** — still years away from being reliable in human-heavy environments.
- **Unit economics** — not a simple labor-savings ROI like other robots.
- **Vendor mindset problem** — developers think they're "selling robots." Customers actually buy *outcomes and value*.

Blueprint Inputs

- Find the right use case — repetitive, predictable, heavy-lifting tasks.
- Prepare for variation — even small changes create "new" tasks.
- Choose the right innovation partner — highly collaborative, shared-risk relationship.
- No human interaction (yet) — initial use cases must avoid human contact for safety.
- Focus on customer value — ROI, efficiency, and pain-point relief, not robot counts.

The Go-To-Market Blueprint

Target customers: Small to medium businesses (less bureaucracy than large brands).

Partnership mode: Collaborative, long-term co-development (not just vendor/customer).

Innovation brand: Partner with companies seen as innovative for PR and credibility.

Industries: Start with **non-regulated sectors** (e.g., e-commerce, apparel, furniture).

Warehouse type: Semi- or highly automated — avoid fully manual warehouses for now.

Pricing model: Value-based pricing (linked to customer outcomes, not robot cost).

Closing Takeaway

- ✓ Equal emphasis on go-to-market strategy and customer value as on R&D.
- ✓ Don't chase flashy demos.
- ✓ Get robots into warehouses with real partners.
- ✓ Success is measured only by customer outcomes and ROI.

Developing Safety Standards for Humanoid Robots

What standard is being built

- **ISO/TC 299 WG12 — ISO 25785-1** recently launched: safety requirements for industrial, dynamically stable mobile robots (includes—but isn't limited to—humanoids).
- "Dynamic stability" is used instead of "humanoids" to cover any robot that must actively control balance; it's a well-established term in research and avoids morphology-only definitions.
- Industrial settings are semi-structured with trained adult workers, making risk assessment tractable.
- Consumer/service spaces (public, home, healthcare) add complexity and diverse users; those will follow later.
- Standards must reflect state of the art - real deployments with data, not just lab demos.
- Standards early enough to guide commercialization; late enough to avoid guessing.

Guidance for developers & vendors (incl. hardware suppliers)

Too early for concrete hardware requirements; focus now on:

- Designing for graceful degradation/fail states (falls, balance loss).
- Functional safety that doesn't assume "power-off is safe."
- Metrics & logging that make risk quantifiable and auditable.
- Engage national committees to influence requirements and align roadmaps.

Core Challenge -Safety (universal theme throughout conference)

- Power-off ≠ safe: unlike statically stable robots, dynamically stable robots may fall when power is cut, so "turning it off" can create hazards.
- Residual risk is higher: balancing + manipulation introduces uncertainty and coupled failures; standards must define acceptable residual risk and how to measure it.
- Need requirements that specify targets, not designs (verify-able outcomes vs prescriptive fixes).

Standardization approach

- Voluntary, consensus-based ISO process; countries adopt nationally for consistent global rules.
- Alternatives (white papers, national-only regs) lack enforceable, harmonized conformity pathways.
- Timeline: project approved May 2025; first meeting July 2025; staged drafts (WD → CD → DIS → FDIS); target publication: May 2028.

Takeaways

- The first standard targets industrial, dynamically stable robots (humanoids included) where balance is actively controlled.
- Safety thinking must invert old assumptions: "stop = safe" may not hold.
- Expect measurable risk targets, harmonized globally, with consumer domains to follow.
- Get involved now: the next 2–3 years are when the hard technical content is set.

How to Keep Humanoids Running All Four Quarters: Why Power Strategy Will Make or Break Humanoid Robotics

The Critical Role of Power in Humanoids

- Power is as decisive to humanoid robotics as AI and mechanics.
- Unlike wheeled or fixed-base robots, humanoids must carry their own battery mass, which drives unique efficiency and runtime challenges.
- Similar to drones, larger batteries don't always extend performance because of added weight.

Current Power Approaches - 3 main methods to power humanoids:

1. Docking/Charging Stations – Traditional but requires robots to leave operations for long periods.
2. Tethering (wired/wireless) – Cheapest and most reliable, but limits mobility.
3. Battery Swapping – Keeps uptime high but adds operational complexity.

- Short, frequent top-ups is becoming a best practice for continuous operation, though humanoids' higher energy draw complicates it.

Unique Energy Demands

- Inference & Compute: Up to half (or more) of energy use comes from onboard AI compute and sensors—not just motion.
- Standby Costs: Simply standing requires ~200–300 watts.
- Fleet Management: Scaling from one robot to hundreds creates charging bottlenecks and facility infrastructure constraints (e.g., breakers tripping if many charge at once).

Looking Ahead (5–10 Years)

- Onboard compute will remain a huge energy consumer, since customers don't want cloud-only dependence.
- AI improvements and more efficient processors may help, but likely overall power budgets will rise before they fall.
- Solutions will mirror the EV world:
  - Fast charging for high-utilization robots.
  - Battery swapping for uptime-critical scenarios.
  - Opportunity charging for mobile bases and downtime integration.
- Infrastructure providers (like WiBotic) are preparing for hybrid solutions that mix these approaches.

Key Takeaway

- **Power strategy is not just an engineering problem but a business enabler**: The success of humanoid robotics depends on balancing runtime, charging methods, infrastructure costs, and compute efficiency to deliver reliable, scalable fleets.

Humanoids in Hospitals: A First Glimpse of Robots as Physicians

Why Humanoids - Healthcare is facing **severe labor shortages** (nurses, doctors, surgeons).

- Robots can help by offering 24/7 availability, Repeatable precision (sub-millimeter), & programmable expertise that can be "downloaded," unlike human training.

Key Challenges in Medical Robotics

- Operating in uncertain, dynamic environments.
- Safety and precision in collaborative settings.
- Dexterous manipulation of medical tools, which require both firm grasping and fine control - current robot hands lack human-level dexterity, compliance, and tactile sensing.

Handling Medical Instruments

- Major barrier is use of standard tools without redesigning them.
- Many instruments require in-hand manipulation (e.g., forceps, clamps, scissors).
- Current robot hands are too large, rigid, and lack rich tactile sensing.

Research Questions

- How to integrate physics-based modeling with AI/data-driven methods.
- How to safely handle deformable objects and tissues.
- How to avoid over-promising: separating fiction vs. reality in humanoid capabilities.
- Balance between teleoperation + machine learning and pure data-driven autonomy.

Key Takeaway

- Humanoid robots in hospitals represent an early but promising frontier. They highlight both opportunities (scalability, precision, new capabilities) and critical challenges (dexterity, safety, autonomy limits). Honest assessment of what works—and what doesn't yet—is vital, especially when patients' lives are involved.

The Shape of General Purpose — Thinking Beyond the Humanoid Form Factor - COBOT

Why Classic Humanoids Struggle in Industry

- Stability & safety: dynamic balance on two feet has a narrow stability margin; failures in sensing, compute, or power → falls.
- Redundancy & reliability: many points of failure (sensors, electrical, actuation). If you lose power, “there’s only one way to go.”
- If you can fence it, use higher-throughput systems; if you must work near people, bipedal risk rises.

Cobot’s Approach (Proxie cobot)

- Focus on moving existing carts (brownfield reality) across hospitals and logistics.
- Deployed in Mayo Clinic: moving up to 1,500-lb carts; in another site, ~1,000 carts/shift in a transload facility.
- Simplify manipulation now (grasp horizontal cart handles); roadmap to boxes/totes later as physical AI matures.
- Why not “smart carts”? On-cart autonomy under-utilizes expensive sensors (carts sit idle ~90% of the time) and complicates ops (load/dispatch/unload handoffs).
- Form follows trust & function: wheels, low center of mass, swappable batteries, robust perception. “Eyes” and design cues signal trustworthiness and appropriate capability (e.g., palms-up grippers, avoid alarming red flashes).

Startup Execution Lessons

- De-risk fast in the field; time = burn. You only learn real performance & ops once deployed.
- A robot must meet three bars:
  - Do real work customers need,
  - Be the best (or among the best) way to do it,
  - Ddeliver compelling ROI.
- Move from pilots to expansions quickly; that’s how you cross the “valley of death.”

KEYNOTE: Advancing Humanoid Robotics Through Generative AI and Simulation” – NVIDIA

The next—and largest—wave of AI is Physical AI → systems that take sensor data + goals to convey actions in the real world. Humanoids are one embodiment, but the stack enables factories, vehicles, and service robots.

Why Now?

- ✓ Labor constraints and rising productivity demands.
- ✓ Manufacturing needs automation.
- ✓ Robotics maturity → toward multi-task, general-purpose capability.

Core Architecture: = Three Computers

- Simulation computer – create/train/test safely at scale (parallel virtual worlds).
- Training computer – data-center scale model training (“robot brain”).
- Runtime/edge computer – on-device inference (latency/bandwidth/safety preclude cloud).

What Simulation Enables

- Design exploration: sensor placement, kinematics, reach, stability, collisions—before building hardware.
- Software-in-the-loop testing across perception/planning/control teams.
- Reinforcement learning at scale: thousands of parallel sims for skills (e.g., robust bipedal walking) under varied friction/forces—impractical/dangerous in the real world.

Closing the Data Gap: GenAI + World Models

- Neural reconstruction: turn camera/LiDAR scans into physically valid digital twins; then auto-generate many variants for generalization.
- World foundation models (“world models”): learn from text+video to supply realistic diversity.
- Sim→Gen pipeline:
  - Teleop a single demonstration →
  - Multiply trajectories in sim (mirrors, poses, start states) with guaranteed physics →
  - Use generative models to vary lighting/textures/materials/backgrounds → tens of thousands of labeled demos.
- “Dreams”: models imagine feasible grasp/placement trajectories for novel objects, expanding training sets beyond seen items.

Q&A

- Quantum computing is promising accelerator long-term; today’s robotics follows the three-computer paradigm.

Takeaway: Generative AI + high-fidelity simulation are the force multipliers that turn scarce real-world data and risky trial-and-error into scalable training and safe deployment for humanoids and other physical AI systems.

Accelerating the Global Physical AI Ecosystem

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How to Unlock Human-Robot Collaboration Through Behavioral Sciences

- Biggest blocker to robot adoption isn't cool demos—it's true human-robot collaboration (HRC).
- To collaborate, robots must understand human behavior, intent, task, and context, not just avoid people.
- **How to Make Robots "Human-Aware"**
  - Use multimodal cues together (no single magic signal): speech, gaze, gestures, body motion, affect, plus scene and task state.
  - Encode environmental norms (hospital vs. theme park vs. warehouse) so the robot knows what behavior is appropriate per setting.
  - Blend modern GenAI/VLMs (great for perception/semantics) with classical, bounded knowledge / ontologies (great for rules, roles, norms).
- Start in structured, repetitive industrial settings (warehouses, assembly lines) where workflows exist and exceptions are manageable.
- Later expand to homes/services (messy, unpredictable, vulnerable users). Requires stronger safety, regulation, and social-norm modeling.

What GenAI Helps (and Doesn't)

- Helps: quicker intent parsing, scene understanding, language grounding, richer labels.
- Doesn't (alone): deliver robust social reasoning or context-specific norms; needs symbolic/bounded representations and behavioral-science inputs.

Human Role

- Robots augment, not replace. Human judgment, creativity, edge-case handling remain essential.

Takeaways

- Invest in multimodal sensing, social-norm libraries per environment, and a hybrid AI stack.
- Design for safety, privacy, and latency from day one.

Betting on a Humanoid Future

What's the real blocker?

- It's not just the form factor. The hard part is functional performance, perception, navigation, dexterous manipulation, safety, and human–robot interaction (HRI).
- Timelines are mismatched**.** Investor horizons are short; robotics needs longer runways.

Function over form

- Perform like a human, not look like one. Sanctuary's lens: move from "it can do it once" to competency (speed + quality customers accept).
- Modularity & environment design may beat strict human-mimicry: change bins/flows/layouts if that gets the job done faster/safely.

Tactile sensing = make-or-break for manipulation

- Need durable, simple, low-cost touch (reliable contact/sensing confirmation across large areas) to keep learned policies stable and work at useful speeds.

Adoption reality (enterprise view)

- Shift from "tech-forward" to value-back. Which tasks justify automation economics?
- Pilots ≠ scale. After the demo, CFOs want operational gains; avoid overpromising huge near-term volumes.
- Educate customers: general-purpose tools must show transfer across multiple tasks/sites, not one bespoke demo.

Toyota Research's playbook for progress

- Make diverse bets (wheels/legs) depending on research vs practicality.
- Use challenge tasks (e.g., in-store "go shopping" tests) to measure quarterly progress and generalization before real deployments.
- Goal: tools users can apply themselves, not one-off solutions.

Investor lens (True Ventures)

- Evaluate problem + environment together; often redesign the environment before adding complex robots.
- Task-focused robots now; general-purpose pays off when reusable building blocks flip the economics.

Collaboration vs lights-out

- Many aspire to "lights-out," but real operations are messy and under-specified; humans still handle edge cases and problem-solving.
- Near term: safe cooperation around people; longer term: more autonomy where it truly pencils out.

Bottom line: Scale comes from proving repeatable competency on economically valuable tasks, enabled by reliable touch, hybrid HRI, and pragmatic environment design—form follows function.