



EMERGING TECH RESEARCH

2021 Annual Artificial Intelligence & Machine Learning Report

VC Trends and Industry Overview

Published Q1 2022





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Published on February 28, 2022

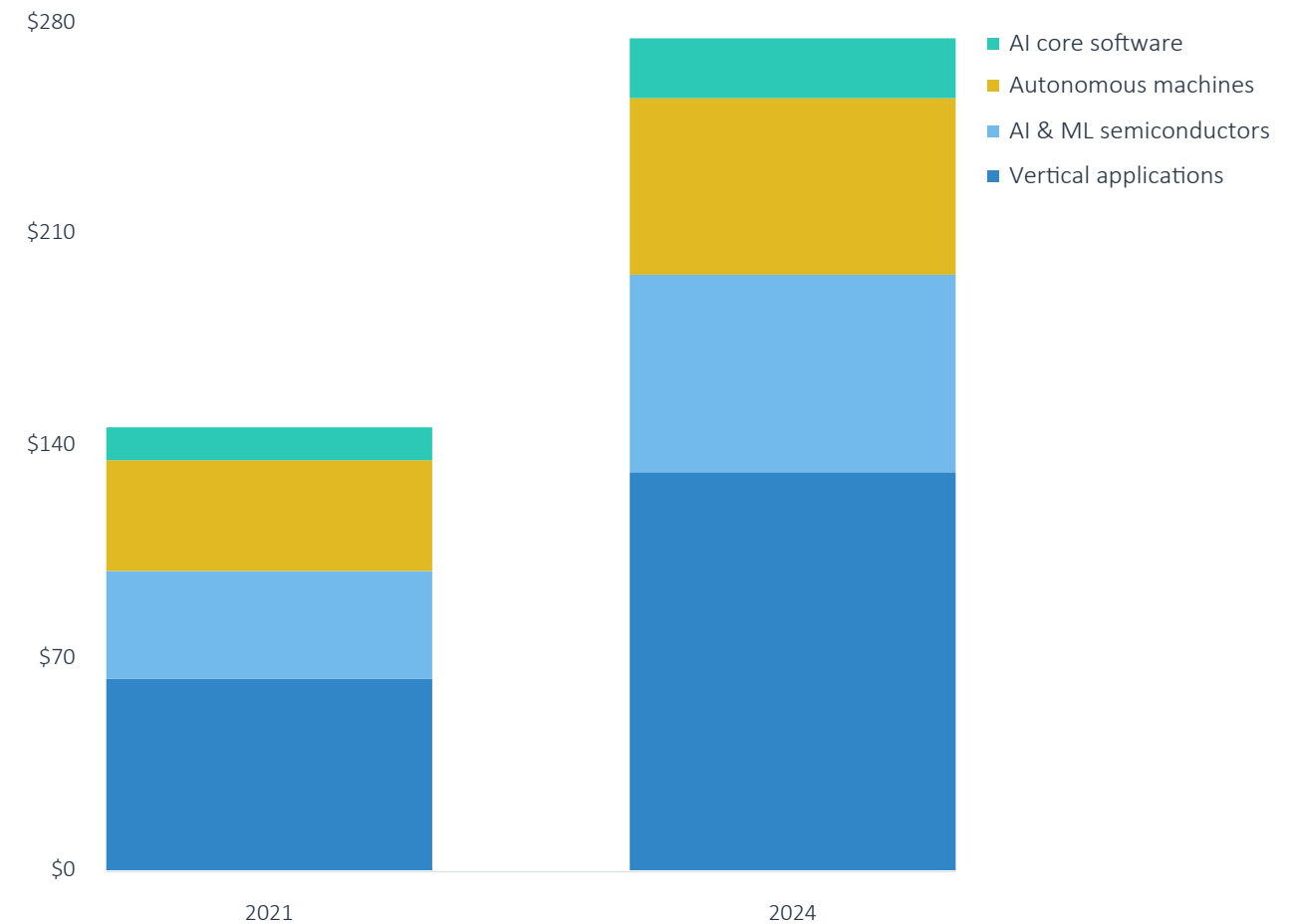


Vertical overview

Artificial intelligence (AI) powered valuation growth for AI leaders and record public listings in 2021. AI leaders grew their share prices significantly during the year, led by **Nvidia** with 125.3% share price growth. In its Q4 2021 earnings call, **Alphabet** (NASDAQ: GOOG) referred to AI as a key differentiator, citing use cases across search, ad targeting, and device personalization.¹ **Microsoft** (NASDAQ: MSFT) cited its partnership with **OpenAI** as a driver for its leadership in enterprise AI, including for code completion and natural language understanding. Cloud-based companies grew strongly while companies that rely on on-premise AI deployments lagged. Recently listed formerly venture capital (VC)-backed companies struggled, with most companies we track losing value during the year. Lending analytics company **Upstart** was a notable exception, growing its share price 271.3% during the year. AI benefits from centralization, and hyperscalers are capturing excess value from the technology.

We estimate the AI & machine learning (ML) market reached \$145.8 billion in 2021, led by the vertical applications segment, along with significant contributions from semiconductors and autonomous machines. AI market research data is improving, given increased research into the attach rates of genuine AI technology to software products. Few AI applications are achieving hypergrowth near 100%, yet many are growing 20% to 30% with the potential to continue growing at a high rate over the next three years. Semiconductor growth is even higher than software, as AI computing becomes a building block of cloud services and intelligent machines. AI core software remains a relatively smaller market at \$10.7 billion, excluding natural language processing (NLP) and computer vision applications that overlap with vertical applications.

Figure 1. AI & ML MARKET SIZE ESTIMATE (\$B)*



Source: PitchBook Emerging Tech Research | Geography: Global | *As of December 31, 2021

1: "Alphabet Inc. Q4 2021 Earnings Conference Call," AlphaStreet, February 1, 2022.

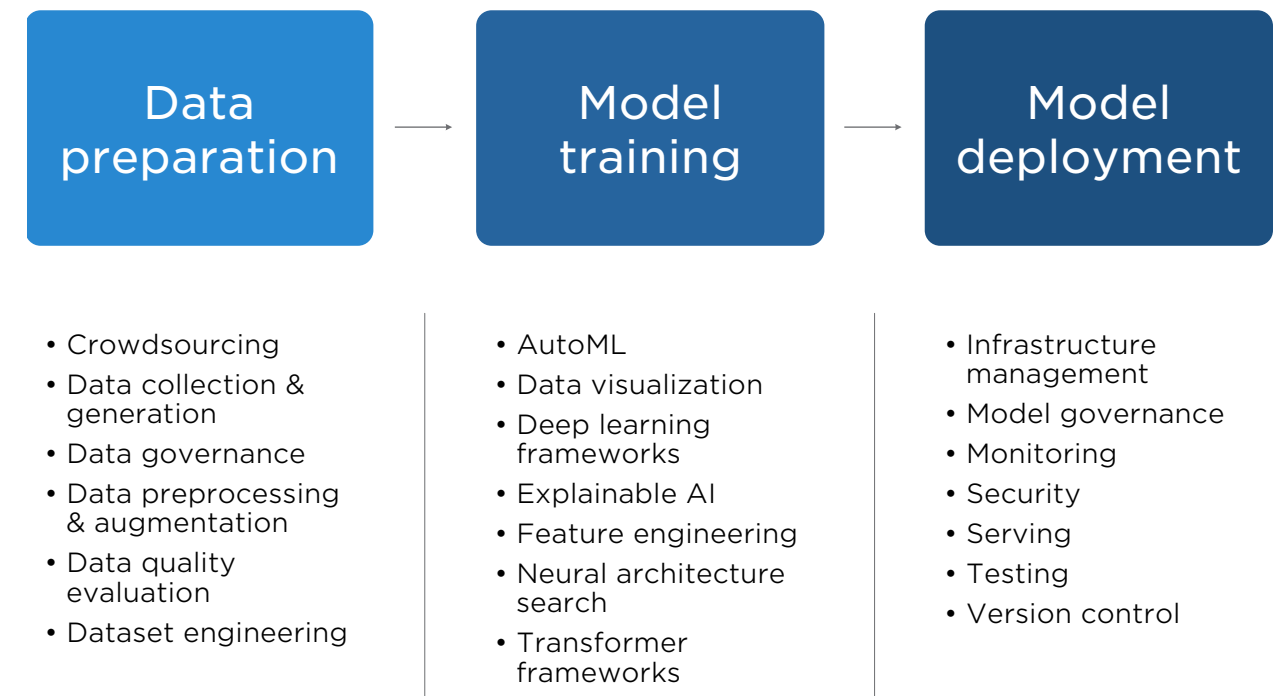


VERTICAL OVERVIEW

Rapid enhancements in model performance are powering continued breakthroughs in AI efficacy. For large language models, **OpenAI** and **Microsoft**'s GPT-3 model has ceded the title of "model with the most parameters" to models including **Google**'s Switch Transformer, **Microsoft** and **Nvidia**'s Megatron-Turing NLG 530B, and Beijing Academy of Artificial Intelligence (BAAI)'s WuDao 2.0 model. This last model includes vision parameters along with text analysis, expanding the possibilities for large models. Transformer models' ability to improve exponentially with more data is encouraging hockey stick growth in training compute for new models, with no end in sight. At a practical level, **Facebook** AI research has been able to use transformers to build multilingual translation models that outperform bilingual translation models for the first time. Furthermore, unicorns including **Disco**, **Grammarly**, and **Doma** are using transformer models to disrupt industries including law, copy editing, and mortgage applications.

The success of these models, along with a shift to cloud database management platforms, is contributing to an unbundling of AI giant platforms. Transformer model training frameworks are available via open-source libraries such as **GitHub** and **Hugging Face**. These models can be optimized for inference on a variety of hardware including central processing units (CPUs) and edge data centers. Startups' ability to provide greater flexibility and reduced inference latency for a range of use cases is encouraging end users to adopt a variety of point solutions to implement these new models. Moreover, the rapid adoption of cloud databases including **Snowflake** and **Databricks** is encouraging the assembly of new data science stacks on top of these platforms instead of within hyperscaler environments. For this reason, we are seeing growth for startups powering data preparation and machine learning operations (MLOps) in these new environments.

Figure 2. POINT SOLUTION OPPORTUNITIES ALONG AI & ML LIFECYCLE



Source: PitchBook

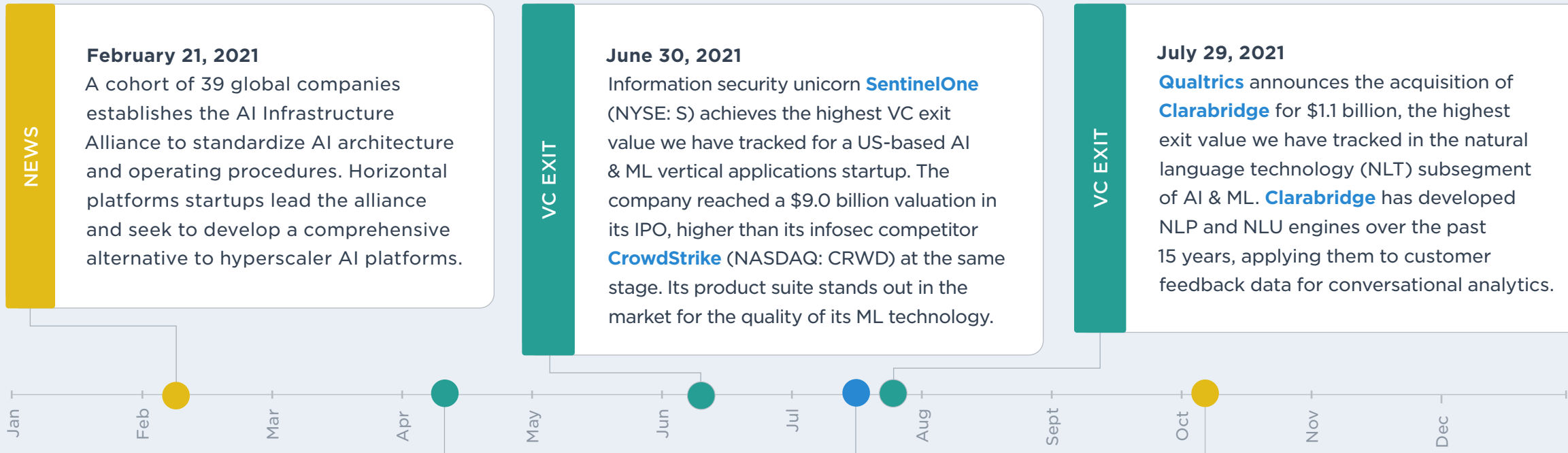


VERTICAL OVERVIEW

We see opportunities for startups to improve the user experience of ML point solutions along the emerging ML lifecycle. In data preparation, insufficient attention has been paid to workflow automation, and a range of solutions are required based on the AI deployments in play. Data quality evaluation and augmentation are emerging solutions to problems born out of manual data cleaning processes. In model training, improving explainability can require specialized solutions for model selection and calculation transparency. In deployment, security and model management are unsolved problems. The value in providing these solutions can be shown by the relative success of AI models in generating profitable businesses.



2021 timeline



NEWS

February 21, 2021
A cohort of 39 global companies establishes the AI Infrastructure Alliance to standardize AI architecture and operating procedures. Horizontal platforms startups lead the alliance and seek to develop a comprehensive alternative to hyperscaler AI platforms.

VC EXIT

June 30, 2021
Information security unicorn **SentinelOne** (NYSE: S) achieves the highest VC exit value we have tracked for a US-based AI & ML vertical applications startup. The company reached a \$9.0 billion valuation in its IPO, higher than its infosec competitor **CrowdStrike** (NASDAQ: CRWD) at the same stage. Its product suite stands out in the market for the quality of its ML technology.

VC EXIT

July 29, 2021
Qualtrics announces the acquisition of **Clarabridge** for \$1.1 billion, the highest exit value we have tracked in the natural language technology (NLT) subsegment of AI & ML. **Clarabridge** has developed NLP and NLU engines over the past 15 years, applying them to customer feedback data for conversational analytics.

VC EXIT

April 12, 2021
Microsoft agrees to acquire **Nuance Communications** (NASDAQ: NUAN) for \$16.0 billion. **Nuance's** leadership in conversational AI—particularly for the healthcare market—justified the transaction. **Microsoft** stated that the acquisition will increase its addressable market in healthcare by around \$250 billion.

VC EXIT/DEAL

July 27, 2021
AI-as-a-service (AlaaS) unicorn **DataRobot** reaches a post-money valuation of \$6.3 billion in its Series G. This round accompanies **DataRobot's** acquisition of **Algorithmia**, a model management startup with backing from **Microsoft** and **Google**. The acquisition compounds the company's advantage in data scientist user experience.

NEWS

October 11, 2021
Microsoft and **Nvidia** announce their Megatron-Turing Natural Language Generation model, surpassing **OpenAI's** GPT-3 model in parameters and reporting unmatched accuracy in complex tasks including reasoning, text completion, and natural language inference.

Q4 DEAL COUNT SUMMARY

1,327
total deals

-12.2%
QoQ growth

7.3%
YoY growth

17.9%
YTD growth

Q4 DEAL VALUE SUMMARY

\$28.0B
total deal value

1.9%
QoQ growth

54.0%
YoY growth

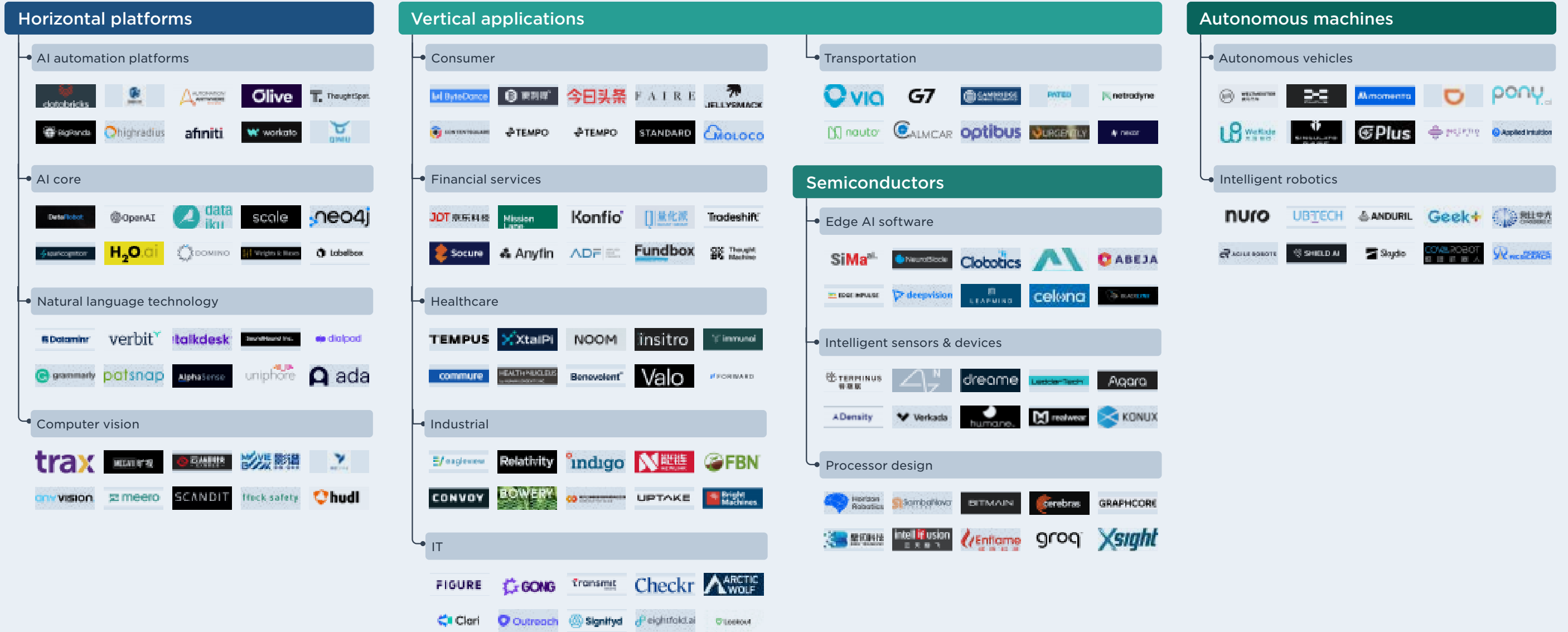
87.2%
YTD growth



AI & ML VC ecosystem market map

[Click to view interactive market map on the PitchBook platform](#)

Market map is a representative overview of venture-backed or growth-stage providers in each segment. Companies listed have received venture capital or other notable private investments.



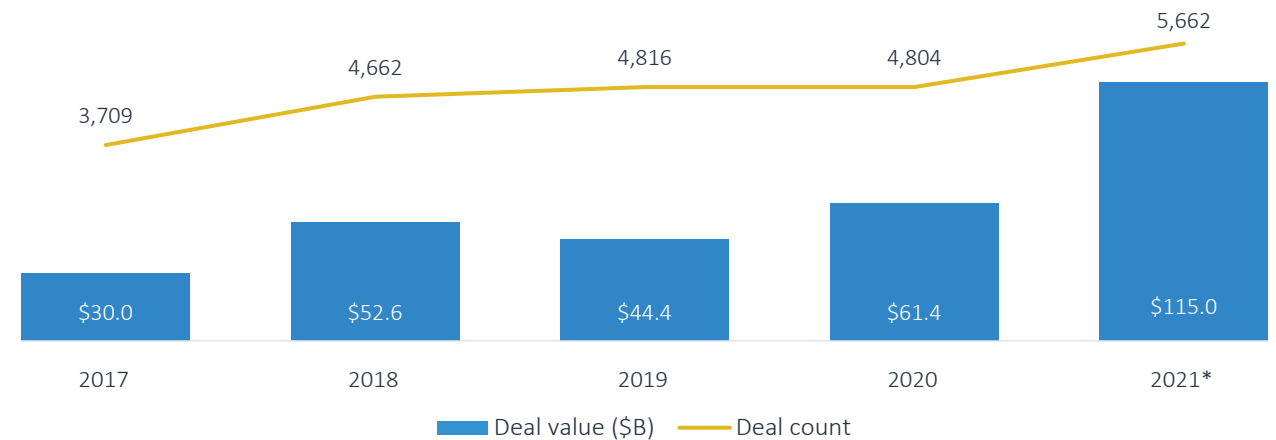


VC activity

AI & ML demonstrated weakness in VC funding relative to technology overall. AI & ML VC deal value grew less robustly than software VC overall, growing only 87.2% from \$61.4 billion in 2020 to \$115.0 billion YoY. US software VC funding grew 131.1% in 2021, yet median late-stage VC deal size in particular only grew 27.7% to \$15.7 million, suggesting muted growth in the volume of high-value VC deals. Deal value in Asia contributed to these muted growth numbers, as we only tracked 62.1% growth in deal value. Some of the hype has departed from pure-play AI companies, as top-performing VC investors dedicated over six times more early-stage and seed deal value to Web3 & decentralized finance (DeFi) than AI & ML in Q3, according to our [Emerging Tech Indicator](#). Deal value is led by applications in healthcare, information technology (IT), and consumer, with each category raising over \$12 billion in 2021.

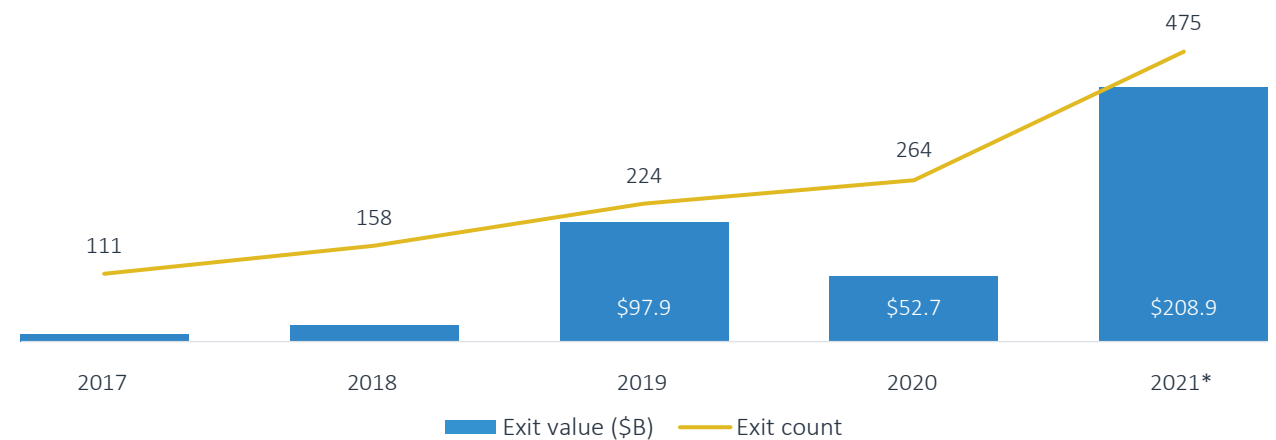
VC exit value swelled during the year, driven by several AI-integrated decacorn exits, though pure-play AI companies did not achieve outstanding outcomes. We tracked \$208.9 billion in exit value across 475 exits, a 79.9% increase in exit count YoY. Public exits more than doubled from 33 to 72, following a theme we have been tracking that AI companies are achieving better outcomes in public markets than via M&A. [Kuaishou](#) and [UIPath](#) contributed over \$80 billion of this total through their IPOs. Autonomous vehicles also contributed over \$20 billion in exits with four SPAC exits and two significant IPOs. We tracked 36 mega-exits in 2021 after only 13 in 2020. In Q4, the trend of AI-integrated mega-acquisitions continued with [Rocket's](#) \$1.6 billion purchase of personal finance startup [Truebill](#). We believe that legacy companies will view \$1 billion-plus AI acquisitions as ways to modernize their businesses.

Figure 3. AI & ML VC DEAL ACTIVITY



Source: PitchBook | Geography: Global | *As of December 31, 2021

Figure 4. AI & ML VC EXIT ACTIVITY



Source: PitchBook | Geography: Global | *As of December 31, 2021

Segment overview

Horizontal platforms

Startups are unbundling hyperscaler AI model platforms into point solutions for specific steps of the ML development lifecycle.

Verticle applications

Fast-growing AI use cases for startups include hospital administration, fleet management, fraud prevention, sales & marketing, human resources automation, proptech, and personal health.

Semiconductors

Incumbent innovation in server processing is creating barriers to entry for data center startups; edge processing can yield greater growth.

Autonomous machines

Autonomous vehicle development efforts require AlaaS to manage training data and safety.



Horizontal platforms

Overview

Horizontal platforms empower end users to build and deploy AI & ML algorithms across a variety of use cases. These platforms directly apply scientific advances in AI & ML research to commercial applications. Companies in this segment have differentiated AI & ML approaches and are built with AI & ML from the ground up—this is also referred to as AI-first. Furthermore, some horizontal platforms are used to improve AI & ML algorithms but do not use AI & ML themselves. Subsegments include:

- **AI core:** Building blocks of AI & ML deployments, including developer tools needed to build and deploy models to production. Categories within this subsegment include AlaaS, AI & ML developer tools, AI platform as a service (PaaS), autoML, cognitive computing, data preparation platforms, quantum AI, and TinyML.
- **Computer vision:** The use of AI & ML to analyze visual data and make meaningful predictions about both the physical world and digital images. The technology can be utilized across use cases to label and make predictions about visual data. Key technologies utilizing computer vision across a range of verticals include AI-enabled augmented reality, computer vision as a service, facial recognition, geospatial analysis, and visual data-labeling software.
- **Natural language technology:** Analysis and interpretation of human communications. NLP uses computational linguistic techniques to learn from communications data and make predictions about the structure and content of language. Companies that apply novel developments in NLP research to commercial use cases are included in this segment,

even if they claim a specific focus such as customer service, legal automation, or contract automation. This field is also referred to as NLP, but we use a broader term to differentiate between companies using only NLP and those applying more recent developments in the field, such as understanding and language generation. Categories within this subsegment include conversational AI, neural machine translation, natural language generation, NLP, and natural language understanding.

- **AI automation platforms:** Software and services that enable enterprises across all verticals to leverage AI to automate critical business processes via predictive analytics. Categories include AI-first applications of the following products: AI for IT operations (AIOps), business intelligence, contract lifecycle management automation, database management, decision intelligence, and intelligent process automation.

Industry drivers

Shortage of data science talent: A lack of data scientists in every industry requires software solutions that can streamline the building and deployment of AI & ML models. 54% of enterprises with some AI deployments perceive a moderate-to-extreme skill gap facing their AI projects, presenting a barrier to becoming mature AI organizations. Consequently, 19% of all respondents of a recent O'Reilly survey reported an AI skills gap as the top barrier to AI adoption. It was the most-cited barrier, although data quality was a close second.²

Security and data integration are common barriers to adoption: AI adopters struggle to leverage their existing databases for AI & ML model building. Common AI & ML frameworks

2: "AI Adoption in the Enterprise 2021," O'Reilly, Mike Loukides, April 19, 2021.



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lack integrations with popular business intelligence and analytics tools, requiring lengthy timelines for data wrangling that do not always result in satisfactory AI & ML models. Furthermore, the requirement of third-party model training produces security vulnerabilities that may not conform to enterprise policies. As a result, enterprises are encouraged to build internal solutions from a medley of open-source and commercial tools that can take months to over a year to coordinate, before a model is even proven to be valuable.

Emerging NLP frameworks: In late 2018, **Google** released BERT (Bidirectional Encoder Representations from Transformers). The framework's innovation of bidirectional text analysis enabled a better contextual understanding of text. Since that time, emerging transformer architectures have achieved state-of-the-art results on a range of NLP tasks.

Improved computing power: **Nvidia**'s recent server CPU named Grace exceeded the performance of its previous DGX systems by 10x for NLP model training, enabling larger training runs and massive neural networks such as the company's collaboration with **Microsoft**, Megatron-Turing 530B.

Enterprise adoption of AI: According to a recent survey, 56% of enterprises across industries have reported using AI in at least one business function, up from 50% in 2020, creating a large addressable market for AI platforms.³

3: "The State of AI in 2021," McKinsey & Company, Michael Chui, et al., December 8, 2021.



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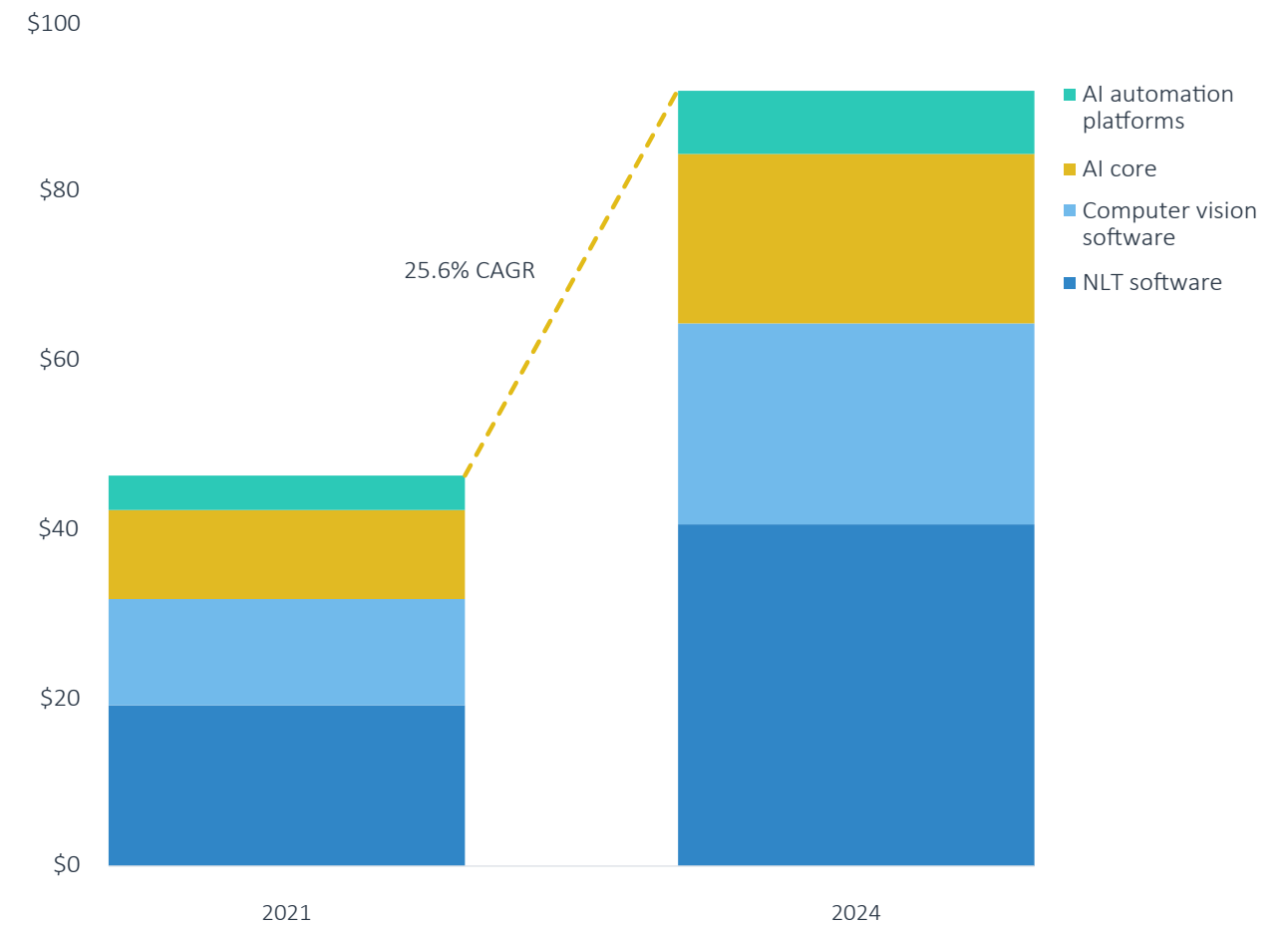
Market size

We estimate that spending on this segment's categories reached \$46.6 billion in 2021 and will grow at a 25.6% CAGR to \$91.8 billion in 2024. This market size includes our estimate of spending on computer vision and NLT applications—even when they overlap with vertical applications spending. We estimate that AI core software, including AI data preparation, model training, and infrastructure platforms, amounted to \$10.7 billion. We revised our NLT estimate upwards to \$19.1 billion in 2021, based on superior attribution of NLP usage to vertical applications in enterprise IT. Computer vision is a slightly smaller market at \$12.4 billion. AI automation platforms, which include AI-integrated business analytics and robotic process automation (RPA) platforms, reached \$4.0 billion in 2021.

Business model

Horizontal platforms typically contain a variety of computational costs, including storage, network, compute, operational, and security. Each of these components has separate costs for both training and deployment. As a result, training a single NLP model can cost around \$50,000 in compute resources. Optional incremental costs include breach discovery and log management, maintenance and support costs, data encryption, and secure web gateways. Startups can unbundle hyperscaler platforms and provide data preprocessing and monitoring on top of the hyperscalers' platform.

Figure 5. HORIZONTAL PLATFORMS MARKET SIZE ESTIMATE (\$B)*



Source: PitchBook Emerging Tech Research | Geography: Global | *As of December 31, 2021



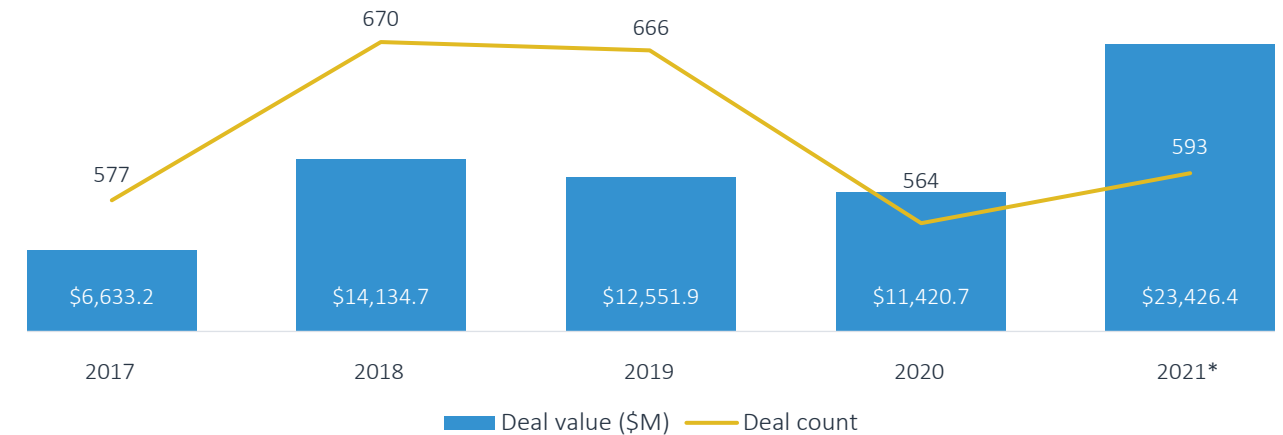
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VC activity

Horizontal platforms VC funding grew 105.1% YoY to \$23.3 billion in 2021. Growth was led by AI core technology including data preparation platforms and model development tools, both of which grew to over \$2 billion in funding from a low base. In the AI automation platform subsegment, database management also had a breakout year, driven by private IPO rounds for data science unicorn **Databricks**. Growth for integrated AlaaS platforms was muted from a higher base, suggesting that some of these platforms are beginning to be unbundled by point solution startups. Strong growth also came from NLP, intelligent process automation, and natural language understanding. Rounds over \$1 billion were raised by **Databricks**, facial recognition giant **SenseTime**, and research leader **OpenAI**. We believe that an emergent stack of ML operations solutions can scale on top of cloud database management platforms such as **Snowflake** and **Databricks**.

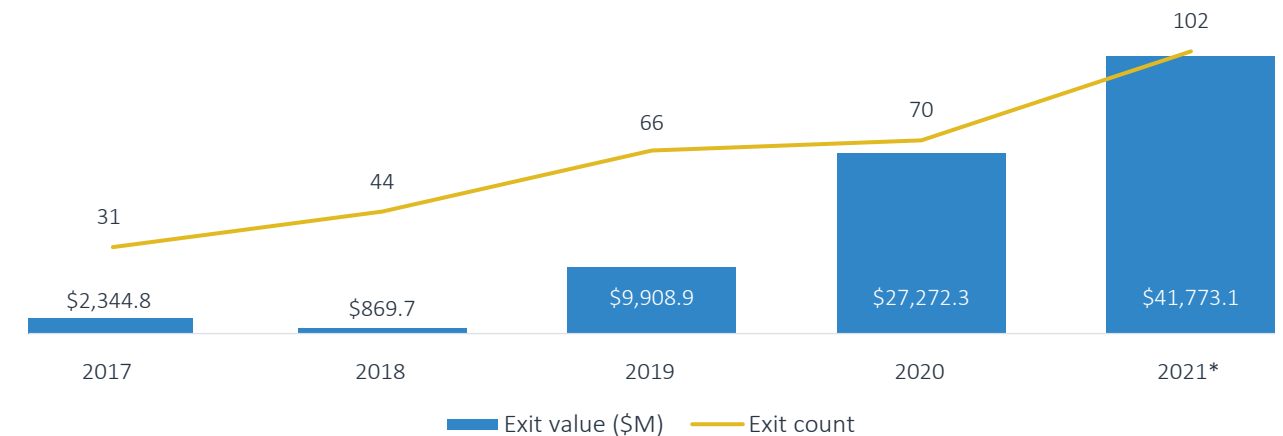
Horizontal platforms VC exits had an outstanding year in both exit value and count, driven by the outlier IPO from **UIPath**, which is not a pure-play AI core software company though it enables AI-driven process automation. The company achieved a \$27.7 billion exit, and we believe that AI-native companies can achieve similar scale in the medium term. Beyond that listing, exit value was driven by acquisitions, including mega-acquisitions over \$1 billion for **Turbonomic**, **Pico Interactive**, and **Clarabridge**. These acquisitions demonstrate appetite for AI-native platforms that apply science to horizontal use cases such as IT management and employee experience. Some of these acquirers include tech giants such as **IBM** and **Qualtrics**. AI giants were minimally active in M&A, with only Meta making a minor acquisition for synthetic data startup **Al.reverie**. 2022's exit activity should be fueled by exits for horizontal AI leaders such as **Databricks**, **DataRobot**, and **Dataiku**.

Figure 6. HORIZONTAL PLATFORMS VC DEAL ACTIVITY



Source: PitchBook | Geography: Global | *As of December 31, 2021

Figure 7. HORIZONTAL PLATFORMS VC EXIT ACTIVITY



Source: PitchBook | Geography: Global | *As of December 31, 2021



HORIZONTAL PLATFORMS

Figure 8.

Key horizontal platforms VC deals over the past year*

COMPANY	CLOSE DATE	SUBSEGMENT	ROUND	DEAL SIZE (\$M)	LEAD INVESTOR(S)	VALUATION STEP-UP
Databricks	August 31, 2021	Database management	Series H	\$1,600.0	Counterpoint Global	1.3x
Dataminr	August 1, 2021	NLP	Series F	\$475.0	KI capital, Valor Equity Partners, Lurra Capital	2.3x
Dataiku	August 5, 2021	AI/ML development platforms	Series E	\$400.0	Tiger Global Management	3.2x
Scale AI	April 13, 2021	Data preparation platforms	Series E	\$325.0	Dragoneer Investment Group, Greenoaks Capital Partners, Tiger Global Management	2.0x
DataRobot	July 27, 2021	AlaaS	Series G	\$300.0	Altimeter Capital Management, Tiger Global Management	2.2x
Grammarly	November 18, 2021	NLP	Late-stage VC	\$200.0	Baillie Gifford	5.6x
Vianai	June 16, 2021	AI/ML development platforms	Series B	\$140.0	SoftBank Investment Advisers	8.4x
Weights & Biases	October 13, 2021	AI/ML development platforms	Series C	\$135.0	Coatue Management, Insight Partners, Qualcomm Ventures, Bond Capital	3.6x
Domino Data Lab	October 5, 2021	AI/ML development platforms	Series F	\$100.0	Great Hill Partners	2.0x
H2O.ai	November 7, 2021	AlaaS	Series E	\$100.0	Commonwealth Bank of Australia	3.8x

Source: PitchBook | Geography: Global | *As of December 31, 2021



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Figure 9.

Key horizontal platforms VC exits over the past year*

COMPANY	CLOSE DATE	SUBSEGMENT	EXIT SIZE (\$M)	EXIT TYPE	ACQUIRER(S)/INDEX
Matterport	July 22, 2021	Computer vision	\$2,260.0	Public listing	Gores Holdings VI
Turbonomic	June 16, 2021	AIOps	\$1,834.0	Acquisition	IBM
Evolv Technology	July 19, 2021	Facial recognition	\$1,227.5	Public listing	NewHold Investment
Clarabridge	October 1, 2021	NLP	\$1,125.0	Acquisition	Qualtrics
Chorus	July 13, 2021	Conversational AI	\$575.0	Acquisition	ZoomInfo Technologies
Neoway	October 19, 2021	Business intelligence	\$331.3	Acquisition	B3
Oculii	November 5, 2021	Computer vision	\$307.5	Acquisition	Ambarella
Element AI	January 8, 2021	AlaaS	\$228.0	Acquisition	ServiceNow
Determined AI	June 21, 2021	AutoML	\$117.0	Acquisition	Hewlett Packard Enterprise
Nanox.AI	November 8, 2021	Computer vision	\$110.0	Acquisition	Nanox

Source: PitchBook | Geography: Global | *As of December 31, 2021



HORIZONTAL PLATFORMS

Figure 10.

Key horizontal platforms incumbents*

COMPANY	SUBSEGMENT	HOLDING STATUS	KEY PRODUCTS	EV/NTM REVENUE
Amazon	AI core	NASDAQ: AMZN	AWS Sagemaker	3.1x
Google	AI core	NASDAQ: GOOGL	TensorFlow	6.1x
IBM	AI core	NASDAQ: IBM	Watson Studio	2.3x
Microsoft	AI core	NASDAQ: MSFT	Azure ML	12.5x
SAP	AI core	ETR: SAP	SAP Intelligence	5.4x

Source: PitchBook | Geography: Global | *As of December 31, 2021



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Opportunities

Transformer models for vision and language: Emerging transformer architectures are beginning to create commercial outcomes in NLP. Transformer models have achieved outstanding results in language processing by learning contextual relationships between words in a sentence, leading to a more human-like understanding of nuance. **Doma Holdings** (NYSE: DOMA), which was formerly called States Title, uses transformers to train models to understand context within real estate documents. The company achieved a \$3.0 billion valuation in its Q3 IPO. Legal tech company **DISCO** (NYSE: LAW) filed a patent for attention-based ML, an approach that closely resembles transformer architecture, before its \$1.6 billion IPO.

In the private market, **Grammarly** uses advanced NLP techniques including transformer models and neural machine translation for spelling and grammar correction. The rapid development of transformer models over the past three years is enabling contextual understanding of language and improving the results of AI-powered sentence completion and copywriting. The company's 5.6x valuation step-up is the highest we have tracked for a late-stage deal since **Snorkel AI**'s 6.8x step-up in August. Emerging natural language techniques such as large language models and conversational AI are resulting in high commercial adoption across industries. As a result, we are seeing opportunities to build large businesses across legacy industries, including hospital administration and insurance claims, that rely on manual data entry of written documents.

Software 2.0: Deep learning can be used to create software applications that perform specific tasks without any human coding. By using the matrix multiplications of neural networks instead of scripts and binary code, ML-powered software can become more reliable and malleable than today's software applications. Its reliability stems from the consistency of model calculations,

which provide an efficient path between instructions and outputs, compared with the brittleness of hand-coded and compiled applications. Its malleability is owed to ML models' ability to retrain themselves based on new information, without requiring software development resources. Such software programs will require a new developer stack that includes interactive developer environments, data preparation platforms, model repositories, and monitoring.

In 2020, rapid revenue growth enabled AI developer platform **Abacus.AI** to raise a \$50.0 Series C at a 3.2x valuation step-up from Tiger Global Management. Its product suite includes unbundled ML model development modules such as model hosting & monitoring, explainable AI, and a real-time ML feature store. It recently announced a computer vision product for image classification. These components are sufficient to build AI applications across ITOps, fraud, demand forecasting, sales & marketing, predictive analytics, and recommendation engines. We expect these use-case-focused AI & ML development platforms to close the gap between data science and business line teams. Ultimately, AI has the potential to overtake the \$271.4 billion enterprise software application industry.

Data-centric AI: In part based on the research of his startup, **LandingAI**, AI pioneer Andrew Ng has promoted the concept of data-centric AI. Ng found that data quality makes a greater impact than model optimization on AI model accuracy—a finding consistent with academic research. Following this theme, activity in data-centric AI is picking up from both investors and founders. Leading language processing startup **Snorkel AI** is marketing itself as a data-centric startup. Former ML engineers from **Google AI**, **Uber** (NYSE: UBER), Stanford's AI Lab, and Carnegie Mellon recently founded Galileo, a data cleaning startup that remains in private alpha. These founders observe that data scientists spend 70% to 80% of their time on data quality and draw upon **Google** Research papers on data-centric AI. VC investors are developing theses around data-centric AI, including a notable thesis by OpenView Venture Partners.⁴



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LandingAI's approach has been validated by a \$57.0 million Series A led by McRock Capital, with participation from Insight Partners and Intel Capital, thus suggesting that leading investors see value in improved data quality.

Data preparation startups are achieving high valuation growth in 2021, which can fuel mega-deals in 2022. In Q3, data-labeling startup **Sama** raised a \$71.0 million Series B from Caisse de dépôt et placement du Québec at a 4.5x valuation step-up. This step-up exceeded the valuation growth of any data preparation, model development, or AlaaS company recorded in H2 2021. Other companies in this space achieving rapid valuation growth over the past two years include **Scale AI** and **Defined.ai**, formerly known as DefinedCrowd. At an early stage, ML is being used for data discovery and annotation by innovators such as Quantum AI. This approach holds promise, given research into self-supervised models. The data-centric AI theme will likely encourage further entrepreneurship to automate data labeling and supply synthetic datasets to supplement human-labeled data.

Risks & considerations

Early attempts at enterprise-wide automation have failed to deliver cost savings: RPA has demonstrated the constraints on enterprise automation. The category has grown quickly and promises to produce strong outcomes for startups. In practice, its implementation has met barriers to fully automating workflows and has been shown to enhance productivity rather than generate real cost savings. RPA implementation often requires specialized developers and scripts that fall apart when unforeseen cases arise. **UiPath** achieved an outlying IPO valuation yet has suffered from a falling share price as its growth normalizes and competitive pressures

4: "The Data-Centric AI Movement and Opportunities for the MLOps Ecosystem," OpenView Partners, Kaitlyn Henry and Maor Fridman, September 14, 2021.

from hyperscalers mount. The segment has continued to grow at a high rate, reflecting enterprises' priority to improve slow and inefficient legacy processes, but highlights its barriers to automating processes across business units.

Public cloud hosts offer comprehensive capabilities for AI & ML model building and deployment: Public cloud hosts can offer AutoML, language, and vision services. They also feature AI marketplaces, including products such as APIs, microservices, datasets, and prebuilt algorithms, that compete with horizontal platforms. Incumbents with offerings in this space include **Alibaba**, **Amazon** (NASDAQ: AMZN), **Apple**, **Baidu**, **Microsoft**, **Google**, **Tencent**, and **IBM**. We believe enterprises with limited budgets can spin up limited AI & ML projects with a combination of open-source frameworks and cloud management tools. For this reason, scaling of multicloud and API-based MLOps tools may be delayed until the return on investment (ROI) for existing AI & ML projects is strong enough to encourage heavier investment in AI & ML capabilities across the enterprise.

AI ethics and regulation: Deep learning is compounding the black box nature of AI & ML as it becomes more effective, because its features are inherently fluctuating and obscure to even the data scientists training them. Models can lack clarity on critical metrics including privacy, security, ethics, and transparency, limiting their utility in sensitive use cases. Active regulatory efforts are ongoing from the US federal government, the EU, China's internet regulator, and the UN High Commissioner for Civil Rights. Explainability is critical to understanding ethical issues in training data bias and discriminatory model parameters but is not available without a ground-up focus during the requirements stage. We believe vendor differentiation will emerge based on the level of model transparency offered.



Vertical applications

Overview

Vertical applications in AI & ML address specific problems within industries and are not always AI first. Many startups in this category design a solution to an industry problem using software and integrate AI & ML to optimize some part of their product. These solutions typically differentiate based on the quality of the dataset used to train the industry-specific model and the industry expertise of the data scientists identifying decision-making areas that can be enhanced by AI & ML models. As a result, many of these startups help automate specific functions within their industry but have limited ability to cross apply their AI & ML to other industries. Subsegments include:

- **AI & ML in financial services:** Includes technologies that embed AI & ML into existing financial services via advanced analytics, process automation, robo-advisors, and self-learning programs. Product categories include financial chatbots, intelligent banking, lending analytics, payment optimization, predictive underwriting, and robo-advisors.
- **AI in healthcare:** Includes technologies that leverage AI & ML to improve medicine and the provision of care. Product categories include AI-based drug discovery, clinical decision support, genetic analytics, healthcare administration, and personal health.
- **Consumer AI:** Includes technologies that use AI & ML to enhance consumer products & services business models. Product categories include AI in media & entertainment, AI & ML advertising technology, digital avatars and gaming, e-commerce recommendation engines, education technology, intelligent price optimization, and smart retail.

- **Industrial AI & ML:** Includes technologies that automate industrial processes and unlock industrial data to find new efficiencies. Product categories include crop maximization, energy grid automation, geospatial analysis, heavy industry automation, Internet of Things (IoT) predictive analytics, supply chain optimization, and telecommunications optimization.
- **AI in IT:** Includes enterprise software tools that optimize specific functions typically administered by IT departments, including both back-end and front-end use cases. Product categories include human resources automation, infosec automation, IT infrastructure management, legal automation, property tech, sales & marketing automation, and software development tools.

Industry drivers

Growing availability of industrial datasets: Two thirds (66%) of surveyed companies are willing to share internal data externally to help develop new AI-enabled efficiencies, products, or even value chains.⁵ Startups can build preliminary models based on data and frameworks from sources including [Google Dataset Search](#), [Kaggle](#), UCI Machine Learning Repository, [Microsoft Coco](#), and [GitHub](#).

Enterprise customers are achieving ROI with AI solutions: McKinsey's State of AI survey found that over 80% of AI adopters in service operations, manufacturing, human resources, and sales & marketing achieved cost savings as a result of their AI projects.⁶ Only around 50% of these adopters reported cost savings the prior year.

5: "The Global AI Agenda: Promise, Reality and a Future of Data Sharing," MIT Technology Review Insights, December 26, 2020.

6: "The State of AI in 2021," McKinsey Institute, December 8, 2021.



VERTICAL APPLICATIONS

Market size

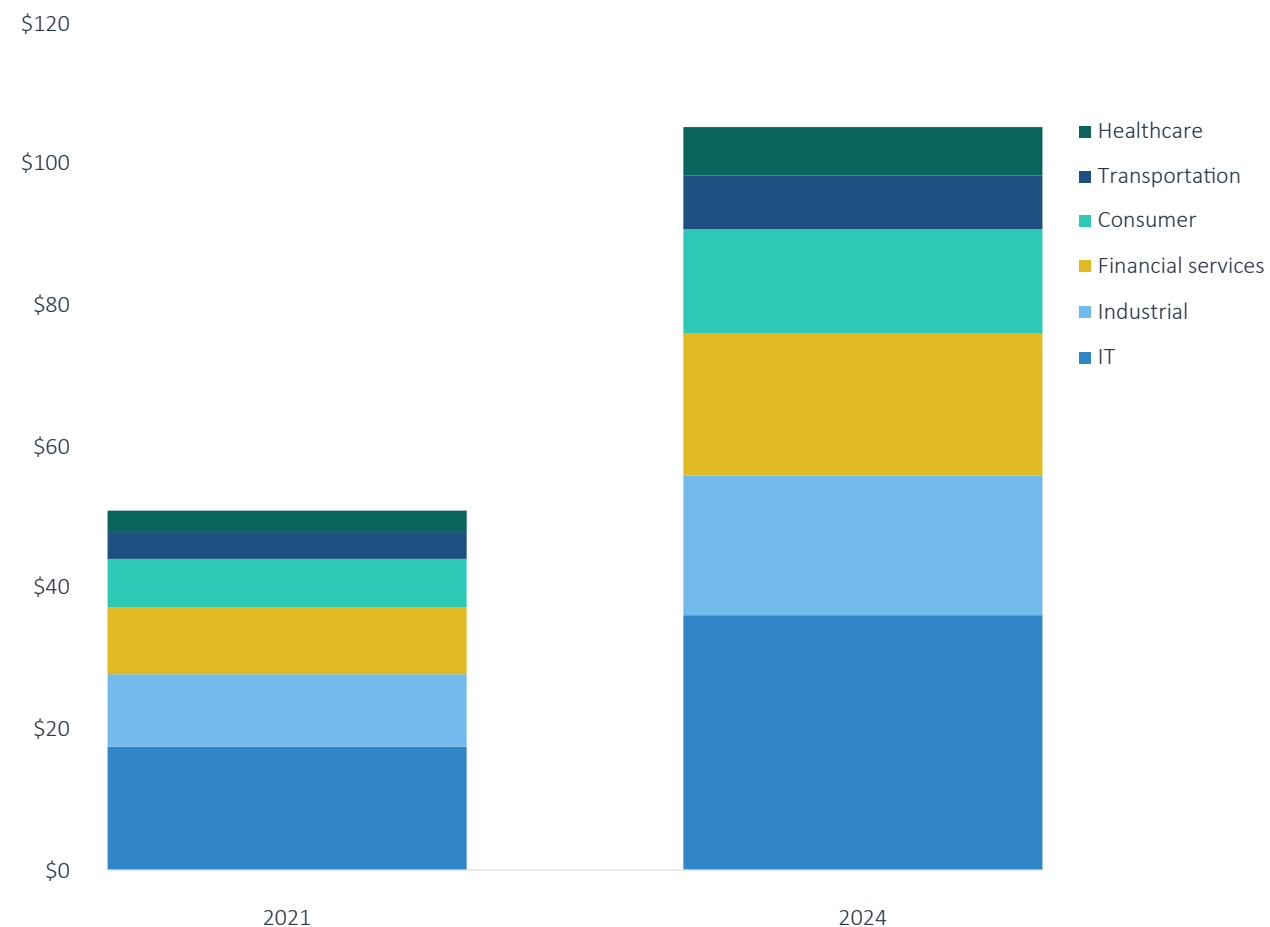
We forecast the vertical applications market to reach \$62.4 billion in 2021, with a 28.1% CAGR out to 2024, resulting in a \$131.0 billion market. The segment is heavily weighted toward enterprise IT applications, which we view as a \$17.6 billion market, led by sales, infosec, and human resources. We forecast IT to grow to a \$46.4 billion market by 2023 at a 27.1% CAGR. We estimate industrial AI to be the second-biggest category at \$10.2 billion, focused primarily on manufacturing automation, supply chain optimization, and predictive maintenance. Both consumer AI and AI in financial services markets are under \$10 billion. Healthcare is a smaller market at \$3.2 billion, but we believe it will grow more quickly than the overall segment at a 28.6% CAGR to a \$6.8 billion market in 2024 as more clinical and genetic data is unlocked for clinical decision support and drug discovery.

Business model

The business models of enterprise AI vendors can vary widely and have considerable influence on their cash flow profiles. Software AI startups employ several key business models including:

- **SaaS:** A monthly subscription that bundles data engineering, model building, and deployment. Additional setup and maintenance fees may be layered on top of a base package. Applications can be delivered as a cloud service through channel partners. In most cases, managed services are required via the vendor or a third-party consulting firm.
- **Codevelopment agreements:** An AI-first vendor partners with an industry specialist to codevelop an AI solution to be used by the industry specialist as a customer and licensed to

Figure 11. VERTICAL APPLICATIONS MARKET SIZE ESTIMATE (B)*



Source: PitchBook Emerging Tech Research | Geography: Global | *As of December 31, 2021



VERTICAL APPLICATIONS

the industry specialist for distribution. Often, this includes an upfront payment to the AI-first vendor to develop the initial models. This arrangement can be necessary to supply AI-first startups with the requisite data to enter a new industry. It is a low-margin business model compared with intellectual property (IP) ownership.

- **Joint venture:** An AI-first vendor and enterprise create a joint venture to develop vertical applications and market them. Typically, the customer is given the choice to buy out the vendor at a future date.

In each case, AI-first vendors bear costs related to data engineering, model building, and maintenance, thereby creating a cost structure that exceeds those of SaaS business models. Consulting firms also arrange outcome-based or upfront capital expenses, though these are not commonly employed by startups. In each case, startups must require customers to consent to data contribution to improve their models without a royalty fee for the customer.



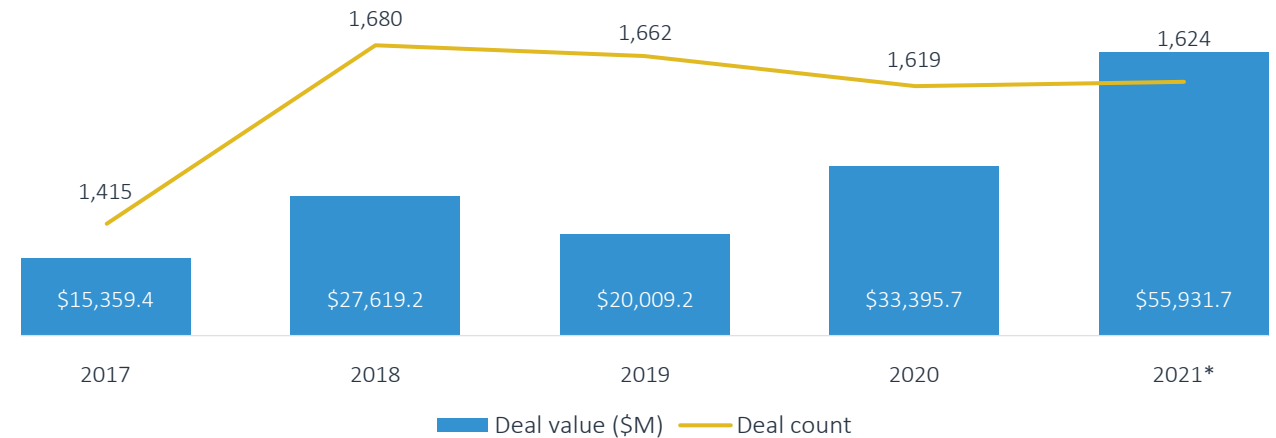
VERTICAL APPLICATIONS

VC activity

Vertical applications VC deal value growth lagged the overall market, growing 67.5% YoY to \$55.9 billion in 2021 with negligible deal count growth. Fast-growing use cases included hospital administration, fleet management, fraud prevention, sales & marketing, human resources automation, proptech, and personal health, all of which raised more than \$1 billion while growing over 200% in VC funding YoY. The relatively low growth can be attributed to the decline of several large categories including banking and retail along with slowing growth in media and drug discovery. **Bytedance** raised an outlying \$5.0 billion round while doubling its valuation. In a similar deal, media unicorn **Jellysmack** raised an outlying \$950.0 million round. VC funding may have been suppressed by the high volume of late-stage companies that achieved exits through public listings and SPAC mergers in 2021.

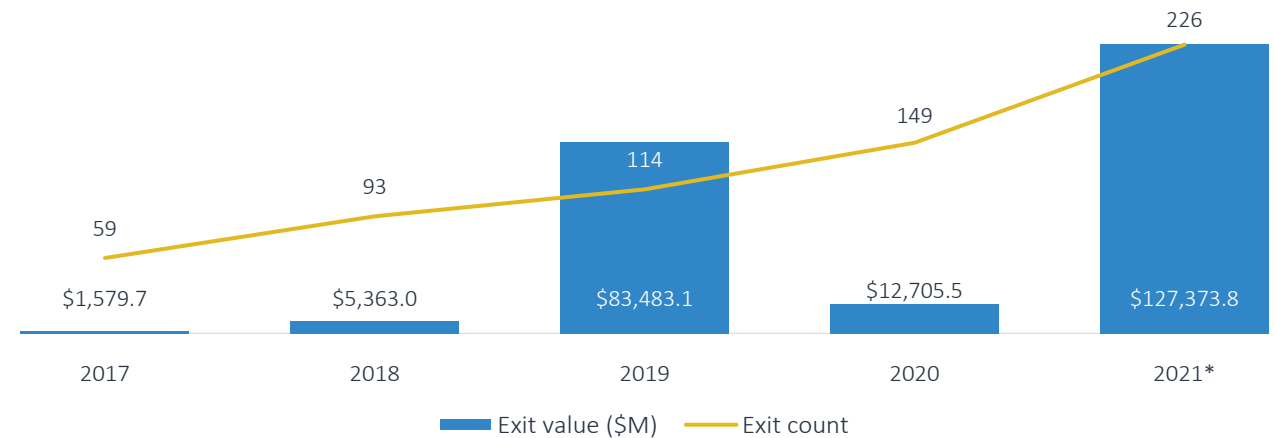
Across categories, AI-integrated companies achieved outstanding public listings in 2021. We tracked a 10x increase in exit value YoY, with vertical applications companies achieving \$127.3 billion in exit value across 2021. Leading use cases included industrial AI, media & entertainment, and infosec, each of which exceeded \$10 billion in exit value. The outlier was mobile media **Kuaishou's** \$55.5 billion IPO, which affirms that AI can power the future of social media. NLP began to power mega-exits in 2021, with **DISCO** and **Doma Holdings** reaching public markets based on the success of their text analysis capabilities for legal automation and mortgage underwriting, respectively. These companies' success should funnel additional capital back into the AI investment ecosystem.

Figure 12. VERTICAL APPLICATIONS VC DEAL ACTIVITY



Source: PitchBook | Geography: Global | *As of December 31, 2021

Figure 13. VERTICAL APPLICATIONS VC EXIT ACTIVITY



Source: PitchBook | Geography: Global | *As of December 31, 2021



VERTICAL APPLICATIONS

Figure 14.

Key vertical applications VC deals over the past year*

COMPANY	CLOSE DATE	SUBSEGMENT	ROUND	DEAL SIZE (\$M)	LEAD INVESTOR(S)	VALUATION STEP-UP
ByteDance	February 28, 2021	AI in media & entertainment	Late-stage VC	\$5,000.0	Funcity Capital, Alanda Capital Management, CSVE Ventures, Streamlined Ventures, 2B Global Capital	2.0x
Jellysmack	May 12, 2021	AI in media & entertainment	Series D	\$950.0	SoftBank Investment Advisors	12.1x
Faire	November 16, 2021	AI-based drug discovery	Series G	\$400.0	D1 Capital Partners, Dragoneer Investment Group, Durable Capital Partners	1.7x
insitro	April 7, 2021	Vertical applications	Series C	\$400.0	Canada Pension Plan Investment Board	3.4x
Checkr	September 1, 2021	Human resources automation	Series E	\$250.0	Durable Capital Partners	2.0x
Incode	December 7, 2021	Fraud prevention	Series B	\$220.0	General Atlantic, SoftBank Latin America Fund	8.6x
Eightfold.ai	June 10, 2021	Human resources automation	Series E	\$220.0	SoftBank Investment Advisers	1.9x
Outreach	June 2, 2021	Sales & marketing	Series G	\$200.0	Premji Invest, STEADFAST Capital Ventures	3.2x
Figure Technologies	May 20, 2021	Proptech	Series D	\$200.0	10T Holdings, Morgan Creek Digital Assets	2.5x
Panther Labs	December 2, 2021	Infosec automation	Series B	\$120.0	Coatue Management	28.4x

Source: PitchBook | Geography: Global | *As of December 31, 2021



VERTICAL APPLICATIONS

Figure 15.

Key vertical applications VC exits over the past year*

COMPANY	CLOSE DATE	SUBSEGMENT	EXIT SIZE (\$M)	EXIT TYPE	ACQUIRER(S)/INDEX
Kuaishou	February 5, 2021	AI in media & entertainment	\$55,516.2	Public listing	Hong Kong Stock Exchange
Samsara	December 15, 2021	Supply chain optimization	\$10,703.5	Public listing	New York Stock Exchange
SentinelOne	June 30, 2021	Infosec automation	\$7,748.0	Public listing	New York Stock Exchange
Doma Holdings	July 28, 2021	Proptech	\$2,355.0	Public listing	Capitol Investment Corp. V
Recursion	April 16, 2021	AI-based drug discovery	\$2,312.0	Public listing	Nasdaq
Berkshire Grey	July 22, 2021	Supply chain optimization	\$2,241.0	Public listing	Revolution Acceleration Acquisition
Darktrace	April 30, 2021	Infosec automation	\$2,179.9	Public listing	London Stock Exchange
MoneyLion	September 23, 2021	AI robo-advisors	\$1,800.0	Public listing	Fusion Acquisition
Hyperconnect	June 17, 2021	AI in media & entertainment	\$1,725.0	Acquisition	Match Group
DISCO	July 21, 2021	Legal automation	\$1,580.1	Public listing	New York Stock Exchange

Source: PitchBook | Geography: Global | *As of December 31, 2021



VERTICAL APPLICATIONS

Figure 16.

Key vertical applications incumbents*

COMPANY	SUBSEGMENT	HOLDING STATUS	KEY PRODUCTS	EV/NTM REVENUE
Recursion Pharmaceuticals	AI in healthcare	NASDAQ: RXRX	Recursion OS	82.0x
Bill.com	AI in financial services	NYSE: BILL	Intelligent Business Payments Platform	45.5x
CrowdStrike	AI in IT	NASDAQ: CRWD	Falcon OverWatch	23.1x
Datadog	AI in IT	NASDAQ: DDOG	Watchdog	39.2x
Aterian	Consumer AI	NASDAQ: ATER	AIMEE E-commerce Engine	0.8x

Source: PitchBook | Geography: Global | *As of December 31, 2021



VERTICAL APPLICATIONS

Opportunities

Drug discovery: Pharmaceutical companies are looking to partner with startups generating IP, rather than those providing AI services. Given the difficulties of integrating software with drug development workflows, large-cap pharma companies prefer to buy patented datasets of molecular targets developed using AI to shorten their drug development lifecycles. AI can be used to shorten a drug development lifecycle from 10 years to as little as three years, if molecular interactions can be accurately predicted in a computational environment. For this reason, pharma companies recognize that startups can generate fresh targets that enhance existing drug pipelines. We believe that large-cap pharma companies will acquire AI startups once successful new ideas are brought to market. In 2021, the AI drug discovery market reached \$613.0 million in spending.

Newer startups are attracting high-value early-stage rounds from top investors. VC investors dedicated \$4.1 billion to the category in 2021, up 42.1% YoY. Early-stage investments in this category have been made less risky by the recent wave of successful IPOs. **Recursion** and **Zymergen**'s recent IPOs demonstrate that, when supplemented by partnerships with Big Pharma companies, AI-first biology startups can generate the data needed to train ML models internally through simulations. Due to the compounding effects of adding more biological samples to enable more experiments, AI's data moats are most apparent in biotech.

The advanced computation required for AI-based drug discovery generates high appetite for capital. Only two years after founding, AI life sciences startup **Valo** raised a \$190.0 million Series B in January 2021 and then upsized the round to \$300.0 million in December. **Valo** considered a SPAC merger at a \$2.8 billion valuation, then canceled it based on market conditions. The company

7: "White House Proposes \$92 Billion IT Budget in FY 2021," **Bloomberg Government**, Chris Cornillie, February 11, 2020.

was incubated by Flagship Pioneering—the same investment firm that seeded **Moderna**. **Valo** focuses on cancer targets by leveraging a compute platform called Opal. Through its partnership with Global Genomics Group, the company has access to patient data—an advantage over other startups that lack clinical data.

National defense: The US Department of Defense's (DoD) investment in AI software is budgeted to reach \$874.0 million in fiscal year 2022 with a 50% increase in AI projects over 2021. Given the strategic priority of competition with adversaries including China, we expect spending to reach \$1.7 billion by 2024. The systems that these AI investments affect are several times more expensive and include vehicle systems and hardware, leading Bloomberg Government to estimate \$5.0 billion in AI-related project spending in fiscal year 2021.⁷

Project Maven is a DoD initiative to build enabling technologies for AI-enabled intelligence gathering, focusing on computer vision analytics for unmanned aircrafts. The project had a \$250.1 million budget in fiscal year 2021 and is reforming its procurement processes to lower buying cycles from 18 months to as few as two months. Furthermore, the project is pushing its prime integrators to consider the best possible capabilities, not the most established companies. As a result, along with **Google** withholding from taking Project Maven contracts, defense-focused startups can achieve significant contract wins. Thus far in Q1 2022, data-labeling unicorn **Scale AI** was awarded a \$250.0 million contract.

At the early stage, former military officials can use their connections to the DoD to commercialize emerging technologies. **CalypsoAI** is the most technically advanced startup we have tracked in the emerging field of ML security (MLSec); it also contracts with the DoD. The startup was founded by former DoD and Defense Advanced Research Projects Agency (DARPA) officials and recently announced a partnership with leading DoD subcontractor ECS that will enable **CalypsoAI** to



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participate in major projects without time-consuming bidding processes. Defense has emerged as a leading use case for horizontal AI platforms **Clarifai** and **CrowdAI**, which recently raised a Series A. Large contract wins are becoming more probable for early-stage startups providing efficiency gains in AI training.

Metaverse: We believe that AI & ML has an important role to play in the creation of a metaverse, which we define as a virtual world in which gaming and social media can come together to create novel interpersonal and entertainment experiences. Meta's new AI Research Supercluster—now one of the fastest supercomputers in the world—is designed to train large language models, which the company views as core to its metaverse ambitions. The compute cluster promises to enable real-time machine translation for multilingual conversations in the metaverse while also detecting abusive content. AI & ML is also necessary for the computer vision behind realistic avatars. We believe that metaverse opportunities will flow to early-stage startups, although this trend is still early for investors. Metaverse innovator Together Labs, the holding company for popular digital avatar game IMVU, raised a \$35.0 million Series E at a 5.3x valuation step-up in Q1. The company uses AI to optimize its monetization targeting and has achieved an outsized impact on growth from the technology. Startups are also using ML to match players with one another. In Q3, game development studio **Singularity 6** raised a \$30.0 million Series B at a 2.9x valuation step-up to build virtual societies that match players with ML predictions. The company has completed pre-alpha testing for its debut open-world multiplayer game called Palia. Game startup **Rune** also graduated from YCombinator to address this opportunity and raised a Series A extension from Makers Fund in Q2.

8: "Aite Matrix: Global Chargeback Guarantee Vendors," Aite Group, November 17, 2020.

Fraud prevention: Startups are bringing advanced ML to a range of fraud-related use cases. ML models can be customized for different customer channels to achieve superior performance and offer guaranteed fraud reduction. Customers are looking for assistance with more than just transaction reviews, including account takeover, false bank declines, and policy abuse. Vendors with multiple models can adapt to anomalous situations across different transaction types, and we believe startups are in the best position to address a range of use cases.

Furthermore, medium-sized merchants seek chargeback guarantees wherein the fraud prevention vendor accepts risk for disputed transactions. Legacy fraud prevention vendors pass liability for disputed transactions on to their customers, thereby limiting their markets to large enterprise customers with sophisticated fraud teams. Chargeback guarantee vendors have found greenfield opportunities among medium-sized e-commerce merchants without sophisticated fraud teams. Most vendors in the chargeback guarantee niche are private, are growing faster than the overall fraud prevention market, and have broken even financially, according to market research.⁸

Fraud prevention unicorns are achieving outstanding valuation growth, particularly among chargeback guarantee vendors. **Riskified** filed to go public soon after Q2, reporting a 64.0% revenue growth in Q1 2021, with \$114.5 million in annualized revenue. The company has helped to create the fraud prevention chargeback guarantee category along with **Forter** and **Signifyd**; both companies grew their valuations more than 2.0x during Q2, with **Forter** raising a \$300.0 million Series F, and **Signifyd** a \$205.0 million Series E. Each of these vendors has slightly different ML approaches and case-resolution methods, thereby resulting in different ideal customer profiles. Additionally, a rising tide of e-commerce transactions is lifting all vendors that serve medium-sized e-commerce merchants. In 2021, identity verification vendor **Socure** grew its post-money valuation from \$375.0 million to \$4.5 billion across two rounds, undergirded by two ML patents. This market is rapidly consolidating into a few winners that have generated sufficient datasets to drive accurate results.



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E-commerce: These recommendation engines are achieving the highest growth in consumer AI, due to the rise in competition with [Amazon](#), which maintains a leading market position in e-commerce, on pace to grow its retail e-commerce market share to 40.4% in 2021.⁹ Its e-commerce business is maintaining double-digit growth, and no other distributor has more than a 10% market share. To service the long tail of the market, a high-growth niche of digital commerce platforms is emerging. [SAP](#), [Shopify](#), [Adobe](#), [Salesforce](#), [BigCommerce](#), and others are challenging [Amazon](#)'s leading market position and integrating AI via native development and third-party partnerships to compete with [Amazon](#)'s personalization engine.

Startups are benefiting from the rapid growth of the [Shopify](#) ecosystem. [Shopify](#) is maintaining high growth during this period of reopening for retail, with its high-margin merchant services growing 47% in Q4.¹⁰ The [Shopify](#) app store contains 373 apps that include the phrase "AI," such as apps for numerous AI startups. Some of the most downloaded paid AI apps on the store are recommendation engines, including those by [Recommendify](#), [LimeSpot](#), and [Extio](#). These recommendation engines enable customer-level personalization incorporating customer, brand, and preference data. Other leading use cases include chatbots, fraud prevention, and ad targeting. [Shopify](#) has become a leading channel for small- and mid-sized-business (SMB)-focused fraud prevention unicorn [Signifyd](#), demonstrating that this community can support large merchant services businesses.

AI is contributing to scale for e-commerce personalization applications, along with improved user experiences. In Q3, [Bluecore](#) became a unicorn with a 3.6x valuation step-up. The company

⁹: "Amazon Dominates US Ecommerce, Though Its Market Share Varies by Category," eMarketer, Blake Droesch, April 27, 2021.

¹⁰: "Shopify Fulfillment Network Moving to Phase Two; Investments Will Accelerate; FVE Down to \$730," Morningstar, Dan Romanoff, February 16, 2022.

optimizes email marketing with predictive product recommendations and audience segmentation, indicating that untapped channels for AI optimization such as email can yield new opportunities. At the early stage, AI startups are finding underserved niches. 2021 saw multiple acquisitions for [Shopify](#) ecosystem participants with Wix.com's acquisition of [Rise.ai](#) and Hootsuite's \$47.9 million acquisition of [Heyday](#). We believe digital commerce leaders will require further acquisitions to maintain pace with [Amazon](#).

Risks & considerations

Excessive fixed costs: We believe AI companies commonly spend 25% or more of their revenue on cloud resources. Commercial language models of around 100 million parameters can cost \$50,000 to train, based on current graphics processing unit (GPU) pricing, and are often retrained on a regular basis. Additionally, images, audio, or video data incur storage costs. Lastly, transferring trained models across cloud environments incurs transfer costs, which can flow to costs of goods sold, if model training is required for each customer engagement. Investors should question how startups utilize cloud resources in their model training and inference.

Overfit models: With large datasets, a model can be trained extensively to the point where it has too many features to make predictions on novel datasets. As a result, some models trained on quality datasets may not have "model-market fit," even if the software solution itself appeals to customers. Startups should engage in early stopping for neural network training and utilize small datasets to avoid this problem.

Racially biased data: Models trained on racially biased data can contribute to racially biased decisions in financial services, human resources automation, healthcare, transportation optimization, and consumer AI. Racial bias in models can emerge from unexpected sources, such as healthcare



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spending data, due to sampling bias and unforeseen features including correlating health spending to health risk. For startups, the public relations consequences of a biased model are material, and racially biased models must be retrained on fresh data with additional feature engineering and testing. The effect of such a restart can amount to millions of dollars. Thus, it can be cost effective to integrate explainability and ethical AI governance frameworks from an early stage to ensure that AI algorithms do not incorporate racial bias in their features or predictions. The negative consequences of bias will gain more public attention as AI & ML are increasingly used in lending and hiring decisions.

Privacy concerns: The retail and advertising industries are another AI & ML end market that is heavily rooted in the use of personal data. With recent lapses in protection and governance of personal data, more concerns will likely emerge surrounding data science products in consumer-centric use cases. Regulatory changes, such as the EU's implementation of General Data Protection Regulation (GDPR), have far-reaching effects on how AI & ML-focused companies need to operate, especially if other jurisdictions follow suit. Adherence to these higher standards will likely add operational costs and could slow implementation in some geographies. This can also affect individual behavior without the intervention of the government, as potential customers may choose an alternative because of privacy concerns.



Semiconductors

Overview

AI & ML model training and inference require hardware with maximum computational efficiency and customized processing for AI calculations. AI requires a high volume of contemporaneous calculations that run in parallel and benefit from specialized chips. Using general purpose chips can cost thousands of times more than using an AI chip for these purposes. As a result, a segment has developed for both the design and software-based optimization of computing hardware, including both semiconductors and sensors. Subsegments include:

AI chips: These types of computer chips attain high efficiency and speed for AI-specific calculations. AI chip optimizations include parallel calculations, low precision calculations to reduce transistor count, AI & ML algorithm compression, and using novel programming languages built specifically to efficiently translate AI computer code for execution on an AI chip. AI chips are faster and more efficient than CPUs by orders of magnitude for the training and inference of AI algorithms. Technologies within this category include:

- Graphics processing units (GPUs)
- Field-programmable gate arrays (FPGAs)
- AI-specific application-specific integrated circuits (ASICs)
- Neural network processors

Edge AI: Compression algorithms that optimize AI & ML models for deployment within various semiconductor environments and edge devices. Technologies in this category include:

- Post-training neural network binarization and quantization algorithms
- Quantization aware training
- Ensemble boosting algorithms
- Edge AI application programming interfaces (APIs) and software development kits (SDKs)

Intelligent sensors & devices: Devices that are optimized to run AI & ML models. This segment contains technologies including:

- Sensors: Devices that measure specific parameters in real-world conditions such as environmental conditions, motion, images, and chemical levels
- Sensor systems: Assemblages of sensors and chipsets that empower specific IoT use cases such as smart buildings, industrial IoT, and connected vehicles

Industry drivers

Expensive computation: The amount of compute being used in large AI training runs has been increasing exponentially. **Nvidia** estimates that the compute required to train leading transformer models is increasing by 275x every two years.¹¹ The cost of the hardware needed for **Google** to train AlphaGoZero has been estimated at \$35 million.¹² **Google** benefited from its proprietary tensor processing units, but similarly ambitious and practical projects undertaken by other companies may require even higher costs to replicate.

Research finding that deep learning improves at scale: The more compute that is used, along with optimal model architecture and large data training sets, the more accurate deep learning algorithms become. This result has been empirically demonstrated by ML researchers and means that additional breakthroughs in accuracy will scale in tandem with computing power.

11: "Investor Presentation: Q3 FY2022," Nvidia, November 22, 2021.

12: "How Much Did AlphaGo Zero Cost?" Dan Huang, Yuzeh, December 2018.



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Demand shifting from discrete to integrated processors: AI chips have focused on the data center but are increasingly shifting to the edge to support emerging use cases including smartphones, tablet computers, wearable devices, and connected automobiles. This is leading to integrated processors growing faster than discrete processors.

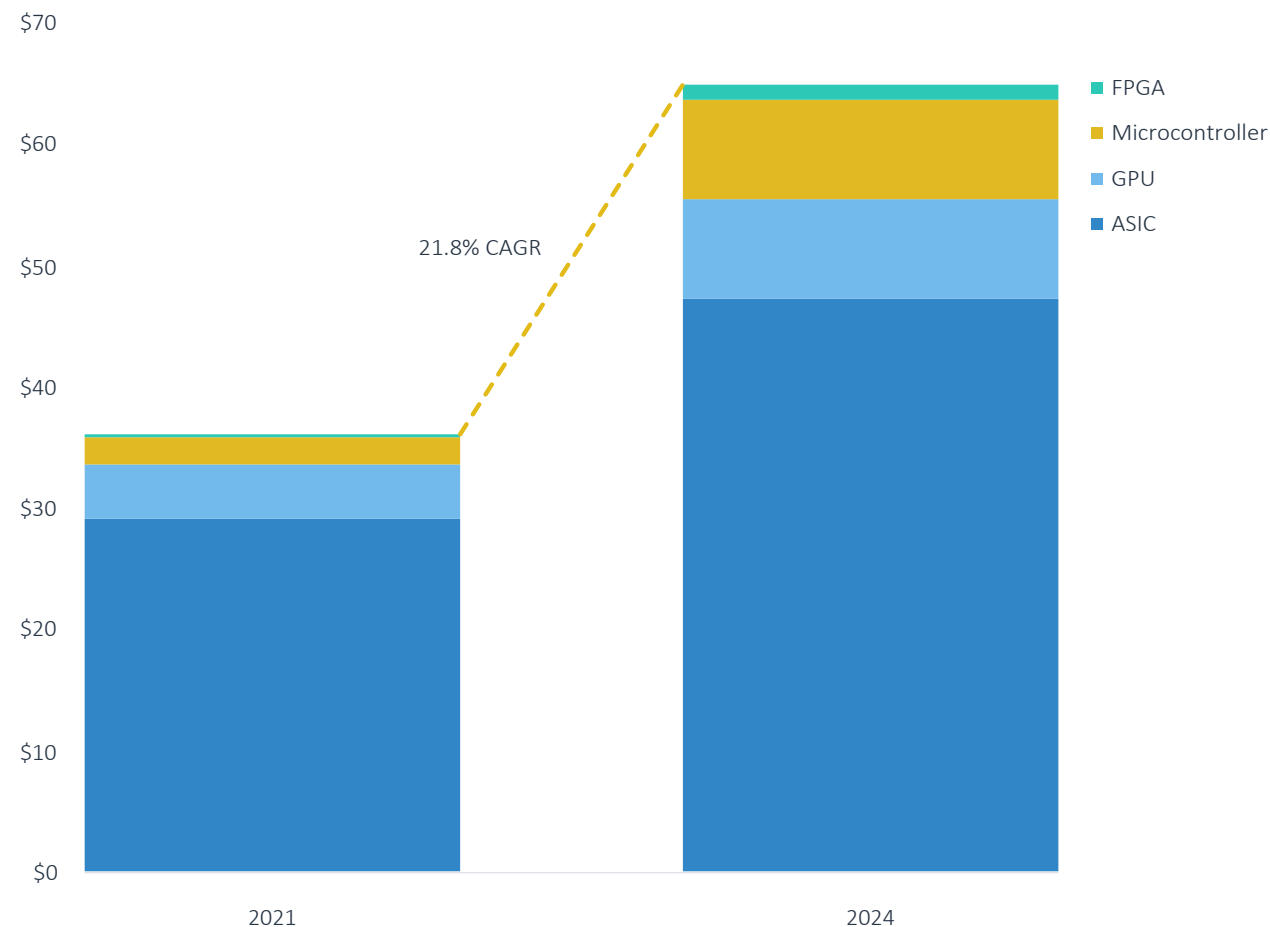
Market size

We estimate the AI & ML semiconductor market will reach \$35.9 billion in 2021, achieving 60.0% growth over 2020 as a result of COVID-19. Over half this total can be attributed to mobile phone ASICs, which will decline as a percentage going forward. We expect the market to grow at a 21.8% CAGR from 2021 to 2024, resulting in a \$64.9 billion market. Our estimate includes all AI semiconductor varieties, such as field-programmable gate arrays, GPUs, microcontrollers, and ASICs. To be included in this estimate, these chips' primary function must be enabling AI processing. We forecast the highest growth segments in this market to be field-programmable gate arrays and microcontrollers, although we anticipate all segments will grow at CAGRs over 50.0% from 2021 to 2024, based on emerging edge AI use cases.

Business model

AI semiconductors are currently deployed through unit sales and usage-based pricing from cloud hosts. For example, **AWS** sells usage-based instances of **Nvidia** GPUs for AI & ML workloads. The usage-based pricing of GPU instances enables around a one-year payback for **AWS** for the underlying hardware, assuming constant usage of these GPUs and given current pricing of around \$14,000 for a standard **Nvidia** Tesla A100. AI & ML developers can thus gain access to GPUs without high capex.

Figure 17. SEMICONDUCTORS MARKET SIZE ESTIMATE (\$B)*



Source: PitchBook Emerging Tech Research | Geography: Global | *As of December 31, 2021



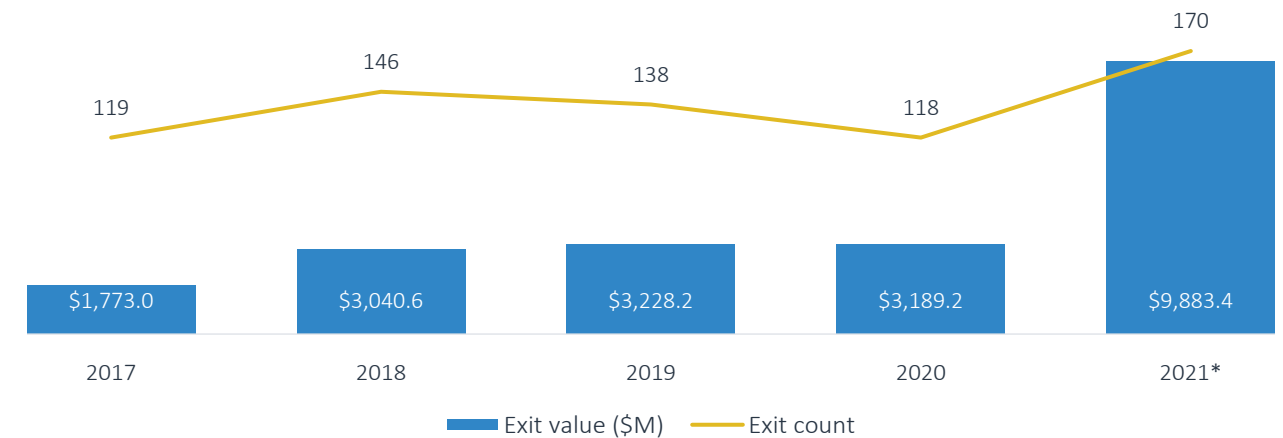
SEMICONDUCTORS

VC activity

Semiconductors had a breakout year in 2021, raising \$9.9 billion, a 209.9% YoY increase. Previously, VC funding had remained flat since 2018. This breakout came against a backdrop of semiconductor shortages and resulting share price growth for semiconductor incumbents. AI computing became the highest-growth area of semiconductors, driving earnings results for chip leaders including **Nvidia** and **AMD** (NASDAQ: AMD). China led mega-deals, with its \$2.3 billion invested in **Horizon Robotics** during the year. Outside of China, data center chip design startups raised outsized deals, including **SambaNova Systems**, **Cerebras Systems**, and **Graphcore**. Edge inference also matured as an investment theme, with mega-deals for **Groq**, **Hailo**, and **Neuralink**.

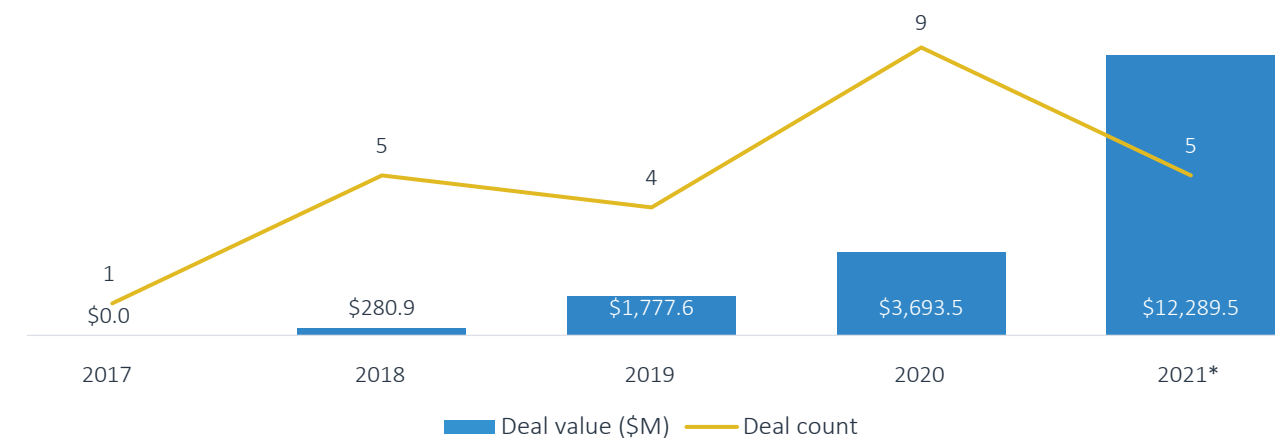
Exit value was more constrained as incumbents worked through regulatory hurdles on pre-existing acquisitions. The only pure-play AI chip exit we tracked was for **Arteris IP** (NASDAQ: AIP), which achieved a \$350.0 million exit in its IPO, with a 6.4x Multiple on Invested Capital (MOIC). The company offers interconnect technology for systems on a chip (SOCs) and benefits from parallel processing for ML, which creates applications in autonomous driving, especially for **Mobileye** and **Intel** (NASDAQ: INTC). Its IPO achieved a 10.2x EV/forward revenue multiple, thus demonstrating a strong growth forecast and comparing favorably to **AMD's** valuation multiple. The failure of **Nvidia's** acquisition of **Arm** may spur more acquisition activity in 2022, along with an IPO for **Arm**.

Figure 18. SEMICONDUCTORS VC DEAL ACTIVITY



Source: PitchBook | Geography: Global | *As of December 31, 2021

Figure 19. SEMICONDUCTORS VC EXIT ACTIVITY



Source: PitchBook | Geography: Global | *As of December 31, 2021



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Figure 20.

Key semiconductors VC deals over the past year*

COMPANY	CLOSE DATE	SUBSEGMENT	ROUND	DEAL SIZE (\$M)	LEAD INVESTOR(S)	VALUATION STEP-UP
SambaNova Systems	April 13, 2021	Chips	Series D	\$678.0	SoftBank Investment Advisers	1.7x
Groq	April 14, 2021	Chips	Series C	\$300.0	D1 Capital Partners, Tiger Global Management	2.6x
Cerebras Systems	November 10, 2021	Chips	Series F	\$250.0	Abu Dhabi Growth Fund, Alpha Wave Global	1.7x
Neuralink	July 30, 2021	Intelligent sensors & devices	Series C	\$205.0	Vy Capital	3.7x
Xsight Labs	December 3, 2021	Chips	Series D	\$150.0	Atreides Management, Valor Equity Partners	1.7x
Hailo	June 23, 2021	Chips	Series C	\$136.0	Gil Agmon, Poalim Equity	4.4x
Humane	July 20, 2021	Intelligent sensors & devices	Series B	\$100.0	Tiger Global Management	5.3x
SiMa ai	May 11, 2021	tinyML	Series B	\$80.0	Fidelity Management & Research	4.1x
Lightmatter	May 6, 2021	Chips	Series B	\$80.0	Viking Global Investors	1.6x
Mythic	May 11, 2021	Chips	Series C	\$70.0	Blackrock Innovation Capital Group, Hewlett Packard Enterprise	1.7x

Source: PitchBook | Geography: Global | *As of December 31, 2021



SEMICONDUCTORS

Figure 21.

Key semiconductors VC exits over the past year*

COMPANY	CLOSE DATE	SUBSEGMENT	EXIT SIZE (\$M)	EXIT TYPE	ACQUIRER(S)/INDEX
Tuya Smart	December 18, 2021	Intelligent sensors & devices	\$10,839.6	Public listing	New York Stock Exchange
Cambricon Technologies	July 20, 2020	Chips	\$3,290.8	Public listing	Shanghai Stock Exchange
Habana Labs	December 16, 2019	Chips	\$1,700.0	Acquisition	Intel
Arteris IP	October 27, 2021	Chips	\$350.0	Public listing	Nasdaq
Xnor.ai	January 8, 2020	tinyML	\$200.0	Acquisition	Apple
Mnubo	July 12, 2019	Intelligent sensors & devices	\$77.6	Acquisition	Aspen Technology
LegUp Computing	October 21, 2020	Edge AI	N/A	Acquisition	Microchip Technology
SensiML	January 4, 2019	Edge AI	N/A	Acquisition	QuickLogic

Source: PitchBook | Geography: Global | *As of December 31, 2021



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Figure 22.

Key semiconductors incumbents*

COMPANY	SUBSEGMENT	HOLDING STATUS	KEY PRODUCTS	EV/NTM REVENUE
Intel	AI chips/edge AI	NASDAQ: INTC	FPGAs for Artificial Intelligence	2.9x
Nvidia	AI chips/edge AI	NASDAQ: NVDA	Tesla V100 GPU	23.1x
AMD	AI chips/edge AI	NASDAQ: AMD	Epyc Processors	8.9x
Lattice Semiconductor	AI chips/edge AI	NASDAQ: LSCC	sensAI Stack	18.4x

Source: PitchBook | Geography: Global | *As of December 31, 2021



SEMICONDUCTORS

Opportunities

Edge AI inference processors: Low-power edge inferencing, referred to as tinyML, is an increasing priority for the semiconductor industry. In Q2 2021, industry standards organization MLPerf released the first results of its Tiny v0.5 benchmark, which measures the performance of neural networks on low-power devices. MLPerf has historically focused on its definitive benchmark for training, and this new benchmark illustrates that edge inferencing is the future of chip design. TinyML-optimized chips require high power efficiency, typically at an energy cost below one milliwatt, with the ability to last on a battery charge for up to one year and with sufficient memory to store compressed inference models. Currently, microcontrollers can contain as little as two kilobytes in memory, while computer vision ML algorithms have been compressed to only around 10 kilobytes. Leading microcontroller manufacturers have identified tinyML as a growth opportunity, thereby presenting barriers to entry for startups. In February 2020, **Arm** announced a chip design targeted for tinyML applications called microNPU, with plans to integrate data memory directly on its processor to achieve 90% energy reductions for ML workloads relative to its existing Cortex microcontrollers. NXP (NASDAQ: NXPI) has recently announced a line of microprocessors based on this platform.

Startups are achieving competitive results for edge AI efficiency compared with leading AI inference engines. A recent vendor benchmarking study found that both **Edge Impulse** and **Plumerai** can achieve competitive results training feed-forward binarized neural networks and 8-bit deep learning models when compared to leading inference engines from **Google's** TensorFlow and chip incumbent **STMicroelectronics** (PAR: STM).¹³ The study focused on the commonly benchmarked computer vision model MobileNetV2 and drew on publicly available

¹³: "The World's Fastest Deep Learning Inference Software for Arm Cortex-M," Plumerai, October 4, 2021.

test results. These startup platforms optimize AI training processes for edge architectures, manipulating the convolutions within deep learning models to minimize memory usage and processing time without pruning the layers of the models themselves. The outstanding results and interoperable platform approaches of startup platforms are enabling partnerships with leading chipmakers.

At the early stage, low-power inference and photonics chips continue to attract funding. In H1 2021, edge inference startup **AlphaICS** achieved a 2.0x valuation step-up in its Series B and gained admission to Silicon Catalyst, a hardware incubator led by semiconductor industry veterans. The company has developed a co-processor optimized for vision applications with less than 50 watts of power, thereby addressing a leading use case for edge AI. Photonics, or the use of laser light in silicon chips for computing, continues to be a leading opportunity for startups, with **Lightmatter** and **Celestial AI** raising large early-stage rounds in H1. Photonics can overcome the limitations of Moore's Law for transistors, thus offering a long-term bet for the future of AI computing.

Data center ASICs: Hyperscalers are moving away from CPUs for AI training, which has resulted in high growth for optimized chip architectures. **Nvidia** remains the market leader in AI training, reporting 55% YoY growth in its Data Center business in Q3 2021. Hyperscalers are opting for its GPUs based on the quality of the company's software and its high efficiency on common benchmarks. Its chips remain power-intensive and thus costly. Going forward, more specialized chip architectures will be needed for specific training processes. As a result, we believe that GPUs could lose market share to chips with higher efficiency and greater utility at customer sites. **Nvidia** has begun to respond to this need with its Grace CPU platform. Custom-built ASICs can achieve high efficiencies based on hardwired circuitry that cannot be configured by developers after production. We believe data center AI ASICs can scale to \$4.0 billion in sales by 2024 from a low base.



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AI chip funding has escalated rapidly, with emerging architectures posing legitimate challenges to incumbents for specific workloads. In Q2 2021, **SambaNova Systems**' \$678.0 million Series D set a VC deal value record for a pure-play AI chip company, making it the most valuable AI chip startup outside of China. **SambaNova** claims that its data center training chips are superior to **Nvidia**'s for training large language models, though it has only recently begun to commercialize and has not been independently benchmarked by industry-leading consortium MLPerf. The round gave the company sufficient funding to tape out a chip at a leading node and sell into the burgeoning data center ASIC market. In Q4, **Cerebras** raised a Series F at a modest valuation step-up of 1.7x.

Considerations

The slowing of Moore's Law threatens deep learning progress: Moore's Law observes an empirical and finite relationship in which transitory density in an integrated circuit doubles every two years, but the time this actually takes has extended. The costs of continuing Moore's Law are justified only because it enables continuing chip improvements, such as transistor efficiency, transistor speed, and the ability to include more specialized circuits in the same chip. The past decade has seen improvements in transistor density slowing. Today, leading chips contain billions of transistors, but they have 15x fewer transistors than they would have if Moore's Law had continued unabated. For this reason, there are constraints on how much innovation is possible in raw processing power.

Chip development is expensive: The cost to design a leading semiconductor at a seven-nanometer node is \$300.0 million, including software, physical design, testing, and tape-out. Chip companies are accustomed to regularly releasing new chips, resulting in an astronomical burn rate for startups.

Semiconductor startups may not scale without a commercially viable architecture: Some advanced semiconductor startups lack the ability to manufacture a cost-competitive chip due to a lack of commercially viable architecture. We believe chip designs with the potential to commercialize and compete with products on the market today must feature the following characteristics:

- Pricing of under \$0.01 per giga floating point operations per second (gigaFLOPS)
- Sufficient funding to bring a chip to production
- Interconnect architectures to optimize data flow between processing and memory
- Compatibility for training and inference software, because some chips require separate software for both processes, which has knock-on effects for software design
- A fabrication node at seven nanometers or below
- Integrated developer kits
- Validation from cloud hosts



Autonomous machines

Overview

Autonomous machines can perform tasks in human-present environments without explicit human control. These machines synthesize ML, computer vision, and datasets of the physical world such as navigation. The segment requires the design of complex hardware with software “brains” and is therefore valued differently than AI & ML software as well as semiconductors. Current applications of AI in robotics lack “common sense” to learn from their environments. This segment does not include optimization of existing robots, including those used in manufacturing and supply chains. Subsegments include:

- **Autonomous vehicle software and design:** Software and hardware solutions that enable self-driving or driver assistance capabilities for cars, trucks, and other on-road vehicles.
- **Intelligent robotics & drone design:** Robotic systems and uncrewed aerial vehicles that can operate without human input. AI & ML can be used for the learning, control, and adaptation of robots. Common applications of autonomous robotics include swimming and picking up, carrying, and putting down objects.
- **Intelligent robotics & drone software platforms:** Operating systems for autonomous robots. These platforms can include fleet management and predictive maintenance.

Industry drivers

Autonomous delivery demand: Because of the closure of retail outlets, last-mile delivery requires additional capacity with less cost sensitivity from merchants. Companies offering autonomous delivery are stepping in to expand the capacity of overstretched delivery networks.

Improving regulatory environment for autonomous vehicles: In December 2020, The National Highway Traffic Safety Administration proposed a new rule for easier certification of autonomous vehicles.

E-commerce growth driving autonomous robotics implementation: E-commerce is projected to grow from 20% to 25% of retail over the next three years, which means warehouses must become more efficient.



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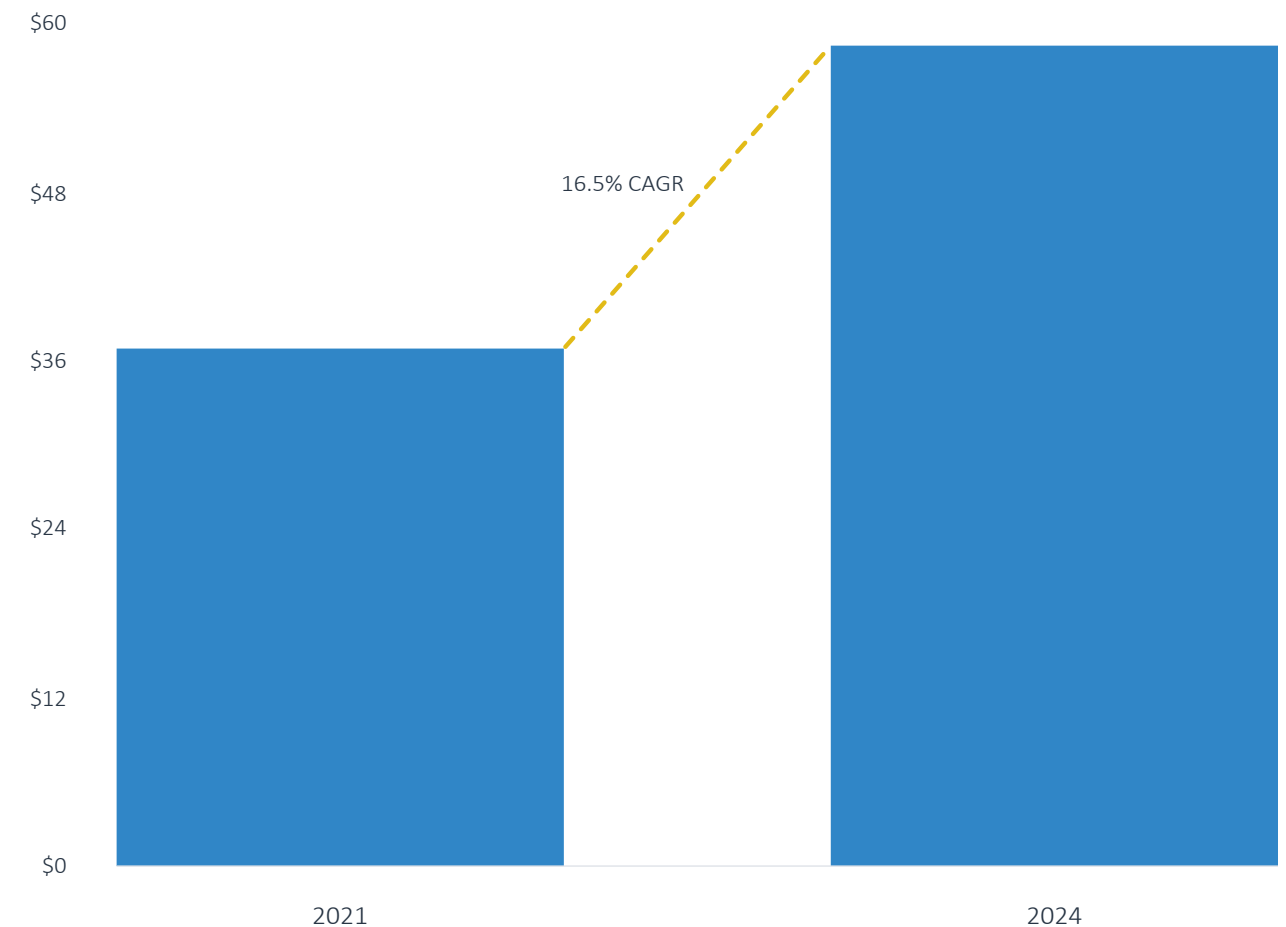
Market size

We estimate the autonomous machines market to be \$36.8 billion as of 2021 and forecast it to grow at a 16.5% CAGR to \$58.2 billion in 2024. This estimate includes commercial and delivery drones, autonomous vehicles, and autonomous robots. This estimate has been revised upward significantly based on existing applications of AI in Levels 2 and 3 autonomous driving. While the industrial robotics market is larger on its own, at over \$100 billion, we focus on the smaller opportunity for autonomous robots within the manufacturing, healthcare, and supply chain industries. Autonomous driving is expected to grow at a 20.7% CAGR through 2024—higher than for robotics, given the challenge of displacing existing industrial robotics in manufacturing and warehouse settings.

Business model

Beyond traditional hardware sales & service business models, autonomous machine suppliers are increasingly delivering robotics as a service to operate with multiple types of hardware. AI & ML algorithms trained for machine intelligence can be deployed on an edge device via software development kits and paid for via recurring revenue. We believe this model is becoming more prevalent among incumbents and is table stakes for startups.

Figure 23. AUTONOMOUS MACHINES MARKET SIZE ESTIMATE (B)*



Source: PitchBook Emerging Tech Research | Geography: Global | *As of December 31, 2021



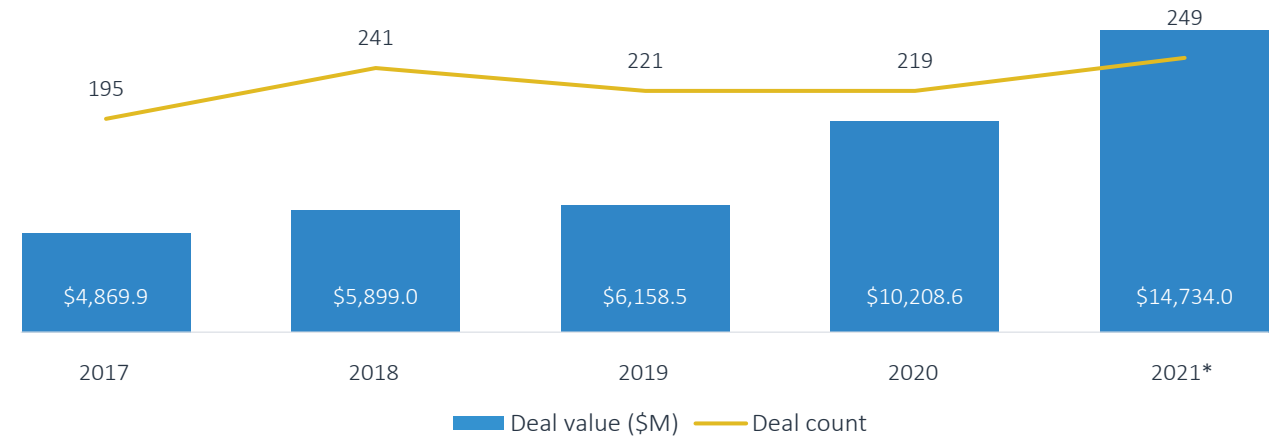
AUTONOMOUS MACHINES

VC activity

The segment's VC funding grew 44.3% in 2021, to \$14.7 billion. Most of this deal value came from autonomous driving mega-deals, led by **Waymo's** \$2.5 billion offering to investors outside of **Alphabet**. Given the success of mobility companies in public markets, institutional investors rushed into the space, including Tiger Global Management, T. Rowe Price (NASDAQ: TROW), and Ontario Teachers' Pension Plan. We did not track outsized valuation step-ups in these mega-deals, as they suggest that the companies compromised on valuation terms to raise outsized deal sizes. Industrial robotics deal activity continued to concentrate in China. We tracked zero pure-play industrial robotics mega-deals in the US, with **Path Robotics** just falling short. Delivery robotics unicorn **Nuro** raised a \$600.0 million Series D to increase its valuation to \$8.6 billion. Drone startups are surpassing factory robotics, given the high growth of **Anduril** and **Skydio**.

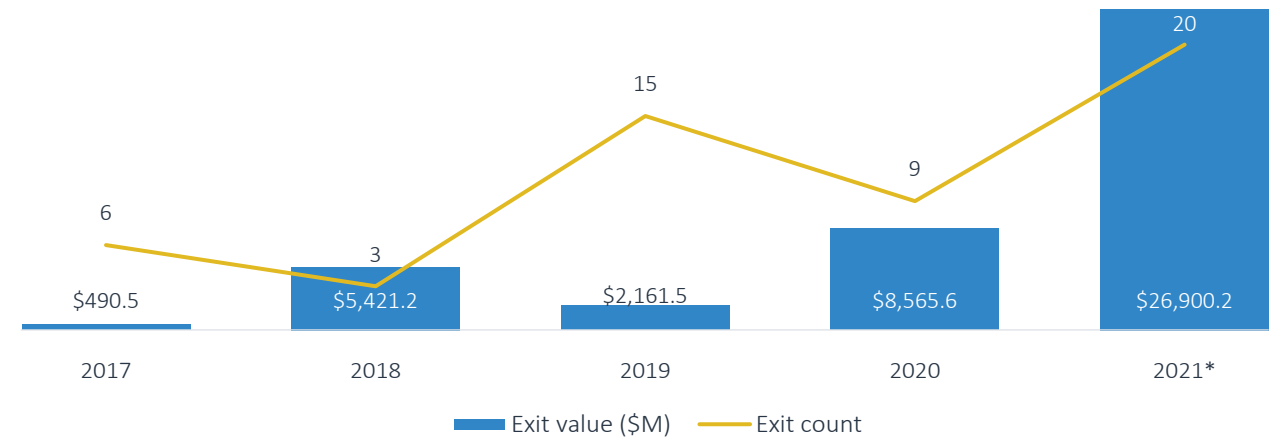
Autonomous vehicles drove a breakout year for exit activity. We tracked 20 exits, with \$26.9 billion in exit value, a 214.0% increase. Nearly all of this total came from public listings, and most of it came from **Aurora** (NASDAQ: AUR) and **TuSimple's** (NASDAQ: TSP) listings. The two companies address different challenges in autonomous driving—passenger cars and trucking. **Aurora** generated a 9.1x MOIC for investors, thereby demonstrating the unparalleled valuation growth opportunity in mobility, as evidenced by **Tesla** (NASDAQ: TSLA) and **Rivian** (NASDAQ: RIVN). Robotics achieved outstanding outcomes for **Bear Flag Robotics**, which **Deere** (NYSE: DE) bought for \$250.0 million, and **Root AI**, which **AppHarvest** (NASDAQ: APPH) bought for \$59.1 million. These acquisitions demonstrate demand for robotics innovation from innovative AI adopters, while AI followers are lagging.

Figure 24. AUTONOMOUS MACHINES VC DEAL ACTIVITY



Source: PitchBook | Geography: Global | *As of December 31, 2021

Figure 25. AUTONOMOUS MACHINES VC EXIT ACTIVITY



Source: PitchBook | Geography: Global | *As of December 31, 2021



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Figure 26.

Key autonomous machines VC deals over the past year*

COMPANY	CLOSE DATE	SUBSEGMENT	ROUND	DEAL SIZE (\$M)	LEAD INVESTOR(S)	VALUATION STEP-UP
Anduril	June 17, 2021	Drones	Series D	\$450.0	Elad Gil	2.2x
Pony.ai	February 7, 2021	Autonomous vehicle software	Series C	\$367.0	Ontario Teachers' Pension Plan	1.6x
Agile Robots	July 9, 2021	Robotics platforms	Series C	\$220.0	SoftBank Investment Advisers	1.1x
Applied Intuition	November 11, 2021	Autonomous vehicle software	Series D	\$175.0	Addition, Coatue Management, Elad Gil	2.7x
Skydio	March 1, 2021	Drones	Series D	\$171.4	Andreessen Horowitz	2.1x
Kodiak	October 22, 2021	Autonomous vehicle software	Series B1	\$125.0	Bridgestone Americas, BMW i Ventures, StepStone Group	1.9x
Path Robotics	July 20, 2021	Industrial robots	Series C	\$100.0	Tiger Global Management	2.8x
Apex.AI	December 14, 2021	Autonomous vehicle software	Series B	\$56.5	Orillion	7.5x
Ambi Robotics	September 14, 2021	Industrial robots	Series A	\$26.0	Tiger Global Management	3.5x
Point One Navigation	November 8, 2021	Autonomous vehicle software	Series A	\$9.9	UP.Partners	2.1x

Source: PitchBook | Geography: Global | *As of December 31, 2021



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Figure 27.

Key autonomous machines VC exits over the past year*

COMPANY	CLOSE DATE	SUBSEGMENT	EXIT SIZE (\$M)	EXIT TYPE	ACQUIRER(S)/INDEX
Aurora	November 4, 2021	Autonomous vehicle software	\$11,022.5	Public listing	Reinvent Technology Partners Y
TuSimple	April 15, 2021	Autonomous vehicle software	\$7,406.6	Public listing	Nasdaq
Embark Trucks	November 10, 2021	Autonomous vehicle design	\$4,546.0	Public listing	Northern Genesis Acquisition II
Aeva	December 11, 2021	Autonomous vehicle design	\$1,537.0	Public listing	InterPrivate Acquisition
AEye	August 18, 2021	Autonomous vehicle design	\$1,290.0	Public listing	CF Finance Acquisition III
Arbe Robotics	October 7, 2021	Autonomous vehicle software	\$354.0	Public listing	Industrial Tech Acquisitions
Bear Flag Robotics	August 5, 2021	Autonomous vehicle software	\$250.0	Acquisition	Deere
Cyngn	October 20, 2021	Autonomous vehicle software	\$172.0	Public listing	Nasdaq
rideOS	June 17, 2021	Autonomous vehicle software	\$115.0	Acquisition	Gopuff
Root AI	April 7, 2021	Industrial robots	\$59.1	Acquisition	AppHarvest

Source: PitchBook | Geography: Global | *As of December 31, 2021



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Figure 28.

Key autonomous machines incumbents*

COMPANY	SUBSEGMENT	HOLDING STATUS	KEY PRODUCTS	EV/NTM REVENUE
ABB	Robotics	SWX: ABBN	ABB Robotics	2.6x
Cognex	Robotics	NASDAQ: CGNX	Vision Guided Robotics	11.8x
iRobot	Robotics	NASDAQ: IRBT	Roomba	0.9x
Stryker	Robotics	NYSE: SYK	Mako Robotic-Arm Assisted Surgery	6.1x
Omron	Robotics	TKS: 6645	Vision Sensors/Machine Vision Systems	2.5x

Source: PitchBook | Geography: Global | *As of December 31, 2021



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Opportunities

AI for autonomous driving: Vehicle ML algorithms struggle to deal with edge cases including unfamiliar objects and scenarios. The first wave of startups collected much of their data from the perspective of the car's sensors, adding real-world data over time through simulation and testing. Some edge cases, including climate, human behavior, stray objects, and the built environment, have separate datasets that can be used to generate their own models. We previously covered [ISEE](#) and [Applied Intuition](#). In its Q4 Series D, [Applied Intuition](#) increased its valuation by 2.7x, to \$3.4 billion pre-money, after achieving outstanding growth in its Series C as well. The company enables autonomous vehicle design companies to customize simulation environments using real-world and synthetic data to mimic edge cases. Also in Q4, [Apex.AI](#) raised a \$56.5 million Series B at a 7.5x valuation step-up. The company offers an operating system for AI in vehicles, robotics, and IoT devices to embed critical safety features in autonomous machines. Automakers are using its software for connected vehicle use cases, providing a faster path to commercialization. We believe point solutions such as these may be easier to commercialize relative to full-stack autonomous driving startups.

Warehouse robotics: Warehouse operators are looking for ways to bridge the manual labor-intensive gap between brick-and-mortar stores and last-mile delivery. [Amazon Robotics](#), formerly [CANVAS Technology](#), has touted this as a competitive advantage based on its vision-based navigation. In Q2 2012, [Berkshire Grey](#)'s (NASDAQ: BGRY) SPAC merger continued a trend of intelligent robotics exits based on high growth prospects in warehouse automation. At 37.3x EV/forward revenue, the deal is priced at a significant valuation premium to robotics incumbents and is justified by AI software, a 68.6% revenue growth forecast for 2021, and continued high growth prospects out to 2025. The company estimates its serviceable

addressable market at \$280 billion based on warehouse labor costs and material handling equipment. We believe the material handling market is materially smaller, at \$5.5 billion as of 2021.

Logistics customers are prioritizing robotics investments to respond to throughput increases and workforce safety needs during the pandemic. Precedent transactions include [Ocado Group](#)'s (LON: OCDO) acquisition of [Kindred AI](#), [Hyundai](#)'s acquisition of [Boston Dynamics](#), and, in 2019, [Amazon](#)'s acquisition of [CANVAS Technology](#). In Q3, soon after emerging from stealth, [Ambi Robotics](#) raised a \$26.0 million Series A to reach a \$106.0 million post-money valuation in a deal led by Tiger Global Management. The company is commercializing domain randomization technology pioneered at UC Berkeley. Similar technology is being used by robotics startup [Covariant](#), also founded by a UC Berkeley researcher.

Autonomous drones: Autonomous drones can unlock new use cases in field monitoring, building monitoring, and extreme environments. We believe construction monitoring is an area of high spending growth, with additional connectivity becoming available in rural areas; autonomous drones can form a central part of its growth story. We estimate the commercial drone market reached \$2.5 billion in 2021 and forecast it to grow at a 26.9% CAGR to \$5.2 billion in 2024.

Startups [Exyn](#), [Embention](#), [vHive](#), [PINC](#), and [PreNav](#) have sensor-enabled drones that address a range of use cases, from supply chain to subterranean mine inspection. [Exyn](#) has developed autonomous drones with multiple embedded sensors that can enter GPS-denied environments such as subterranean mines. [Skydio](#)'s \$171.4 million Series D in Q3 achieved a 2.1x valuation step-up to a \$1.1 billion valuation and demonstrates that drones are shifting from early adoption by consumers to widespread adoption by enterprises for diverse use cases. [Skydio](#)



AUTONOMOUS MACHINES

signed the largest-ever enterprise drone deal in 2020 with [EagleView](#), a roof measurement company, and is scaling with local governments for infrastructure inspection.

Risks & considerations

Products killed before commercialization: The lag between product announcements and launch dates can last over a year. During this time, technical roadblocks can emerge, and cost overruns can reduce the economics of already low-margin hardware products. Robotics teams should have extensive experience with go-to-market strategies to overcome these commercialization hurdles.

Robots in human-present environments failing in the field: As new use cases emerge, robotics companies are struggling to turn proofs of concept into sticky revenue. [SoftBank Robotics](#) has faced high churn on its robot-as-a-service contracts, pressuring it to shorten the three-year length of its contracts.

Regulatory risk: In autonomous vehicles and mobile robotics, uncertainty around regulatory frameworks may limit the growth of emerging technologies. The National Highway Traffic Safety Administration currently does not exempt self-driving cars from occupant safety standards, thus limiting the benefits of driverless technology. In robotics, regulation might be reactive to the introduction of robots in human-present environments, which creates risk along with innovation in domain randomization.

Appendix



APPENDIX

Figure 29.

Top VC-backed AI & ML companies by total VC raised to date*

COMPANY NAME	VC RAISED TO DATE (\$B)	SEGMENT	SUBSEGMENT
ByteDance	\$13,115.0	Vertical applications	AI in media & entertainment
Waymo	\$5,500.0	Autonomous machines	Autonomous vehicle design
Databricks	\$3,497.4	Horizontal platforms	Database management
Horizon Robotics	\$3,400.0	Semiconductors	Chips
JD Digits	\$3,141.3	Vertical applications	Intelligent banking
Nuro	\$2,132.0	Autonomous machines	Industrial robots
Bianlifeng	\$1,533.0	Vertical applications	Smart stores
Relativity	\$1,334.5	Vertical applications	industrial automation
Ubtech	\$1,266.5	Autonomous machines	Humanoid robotics
Face++	\$1,258.0	Horizontal platforms	Computer vision

Source: PitchBook | Geography: Global | *As of December 31, 2021



APPENDIX

Figure 30.

Top strategic acquirers of AI & ML companies since 2021*

NAME	DEAL COUNT
Accenture	6
FiscalNote	4
Woven Planet Holdings	3
Discord	3
Coinbase	3
Qualcomm	3
Cisco Systems	3
DataRobot	3
Atos	3
LivePerson	3

Source: PitchBook | Geography: Global | *As of December 31, 2021

Figure 31.

Top VC investors in AI & ML companies since 2021*

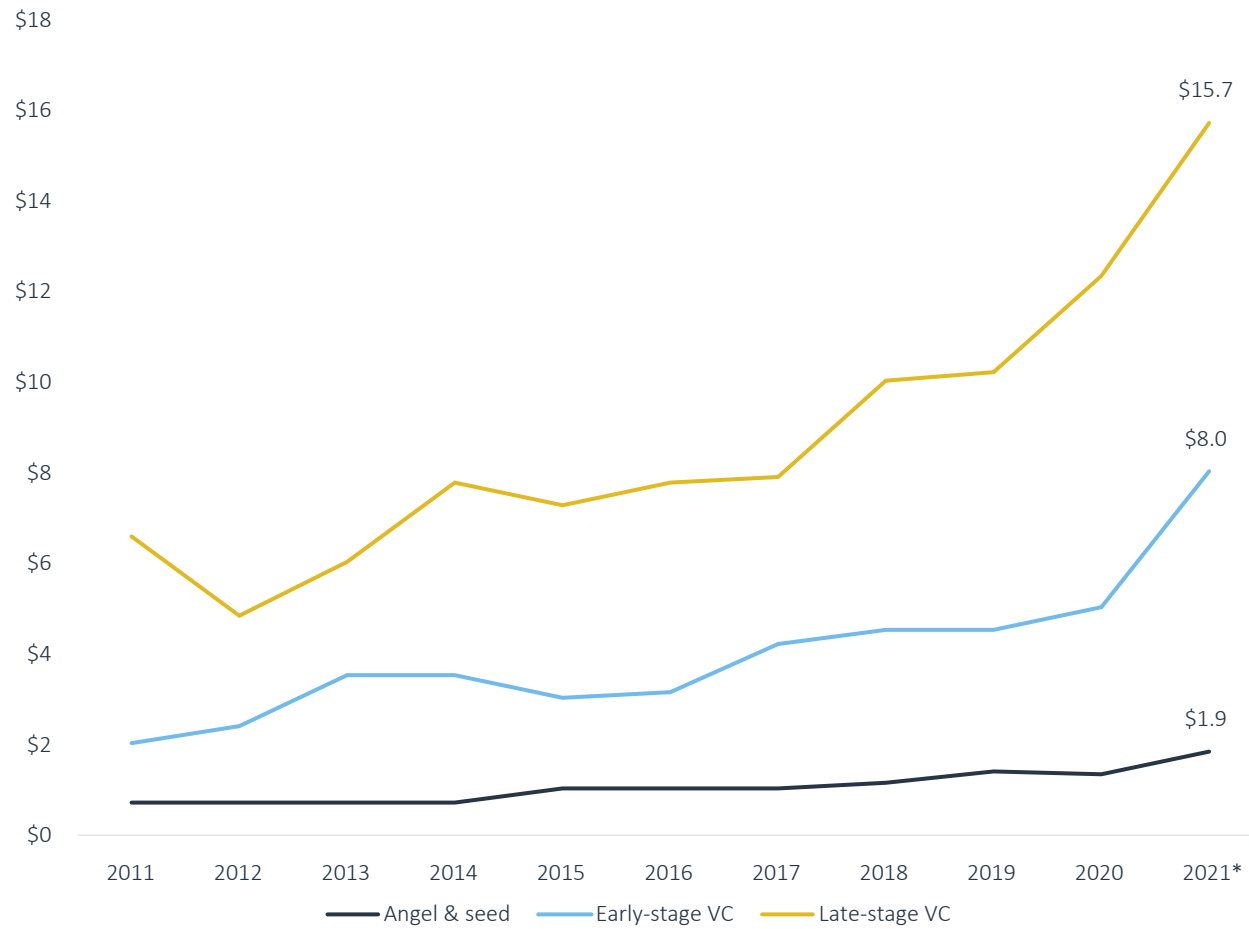
NAME	DEAL COUNT
Sequoia Capital China	237
Accel	217
Khosla Ventures	211
Intel Capital	203
500 Global	193
Right Side Capital Management	192
New Enterprise Associates	187
Alumni Ventures	181
GV	177
Andreessen Horowitz	174

Source: PitchBook | Geography: Global | *As of December 31, 2021



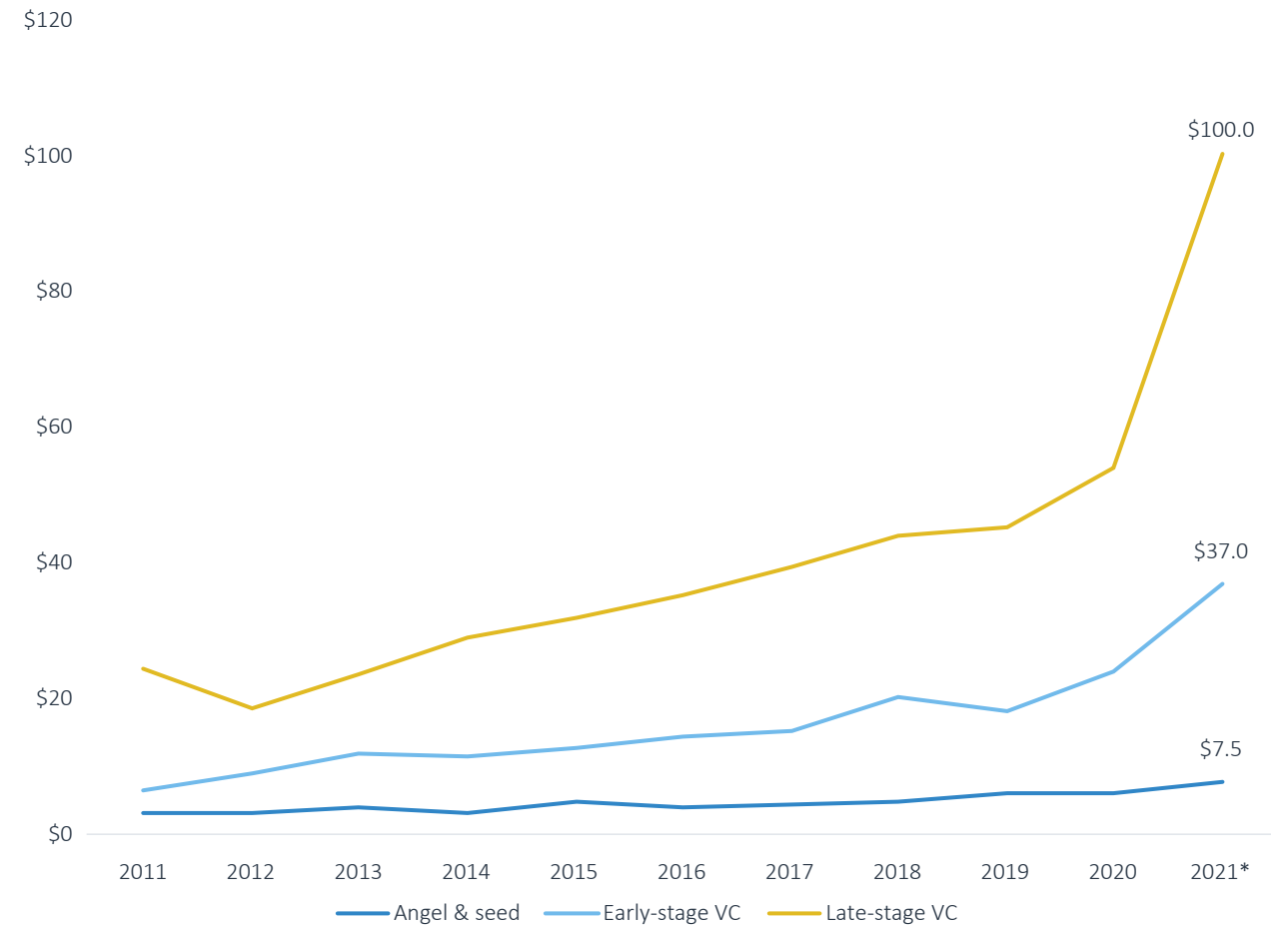
APPENDIX

Figure 32. MEDIAN AI & ML VC DEAL SIZES (\$M)



Source: PitchBook | Geography: Global | *As of December 31, 2021

Figure 33. MEDIAN AI & ML PRE-MONEY VALUATIONS (\$M)

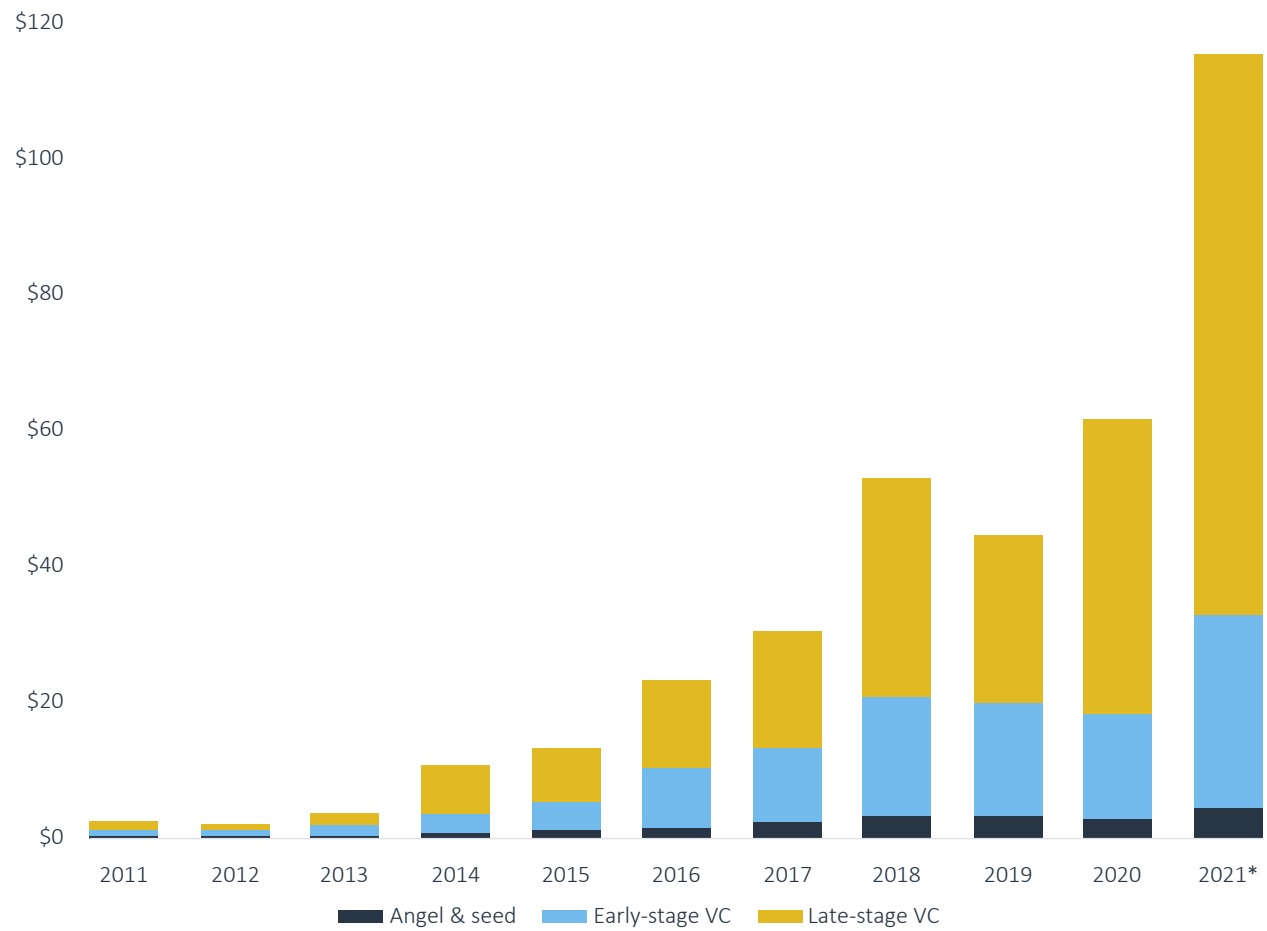


Source: PitchBook | Geography: Global | *As of December 31, 2021



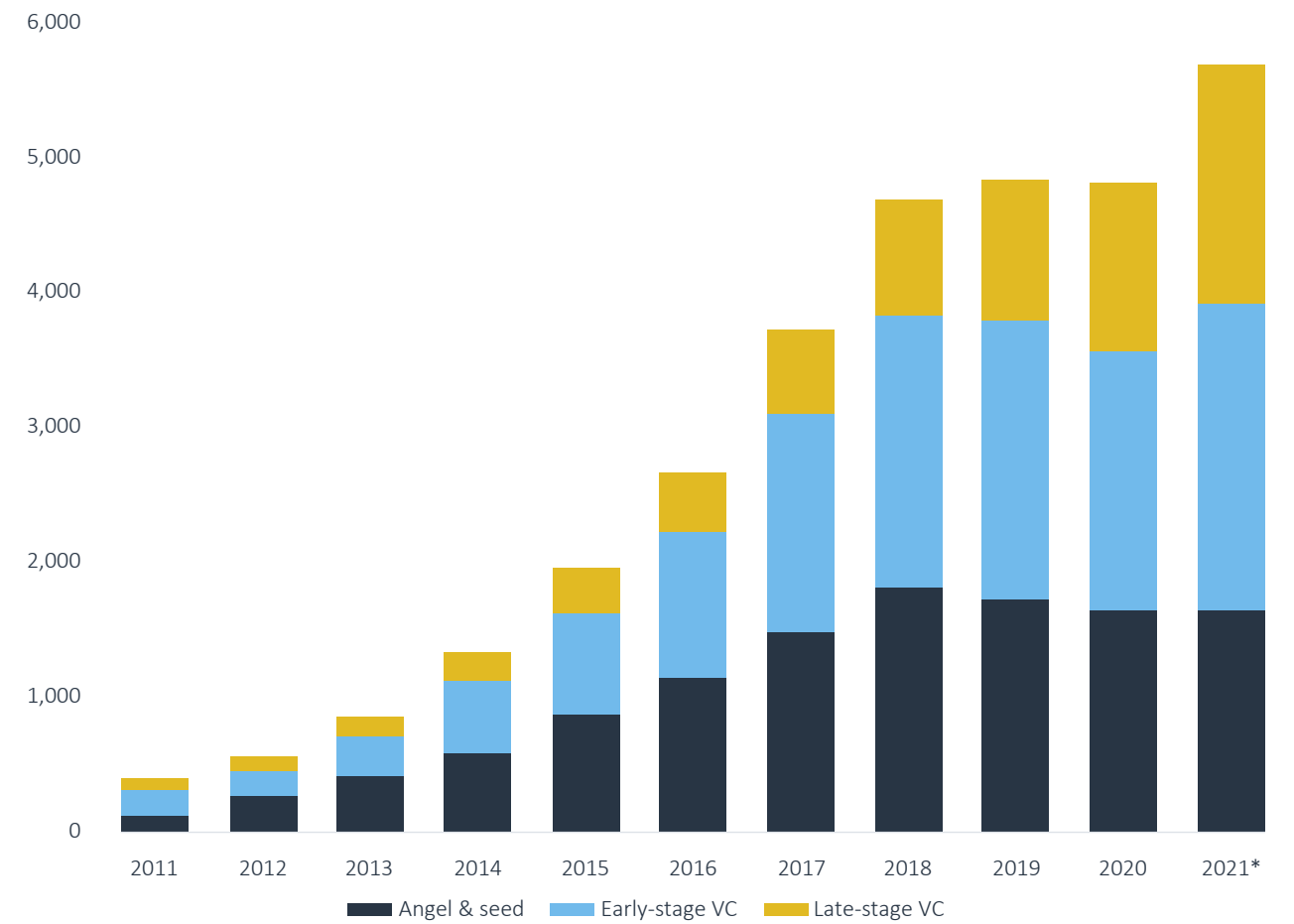
APPENDIX

Figure 34. AI & ML VC DEAL VALUE (\$B) BY STAGE



Source: PitchBook | Geography: Global | *As of December 31, 2021

Figure 35. AI & ML VC DEAL COUNT BY STAGE

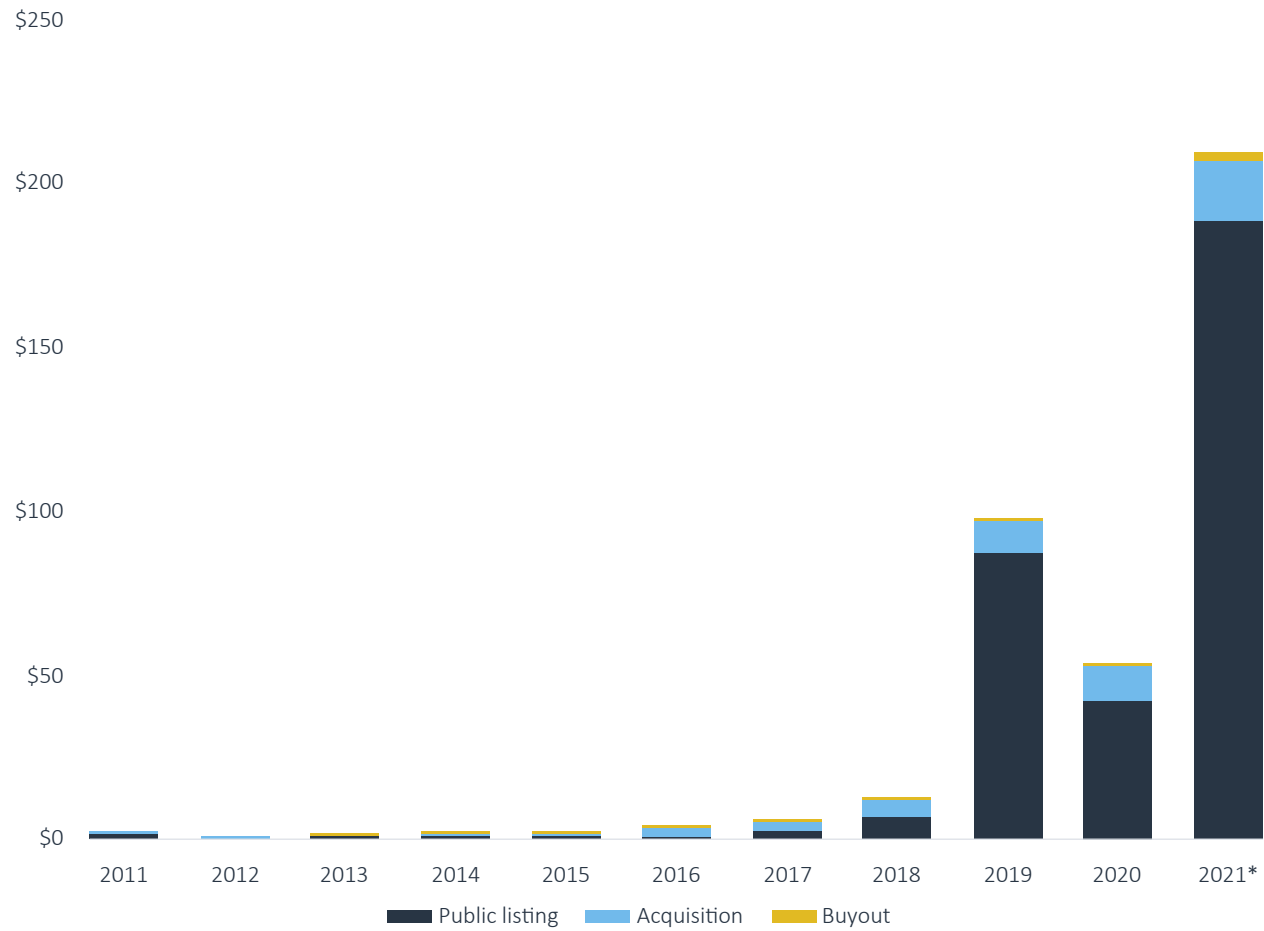


Source: PitchBook | Geography: Global | *As of December 31, 2021



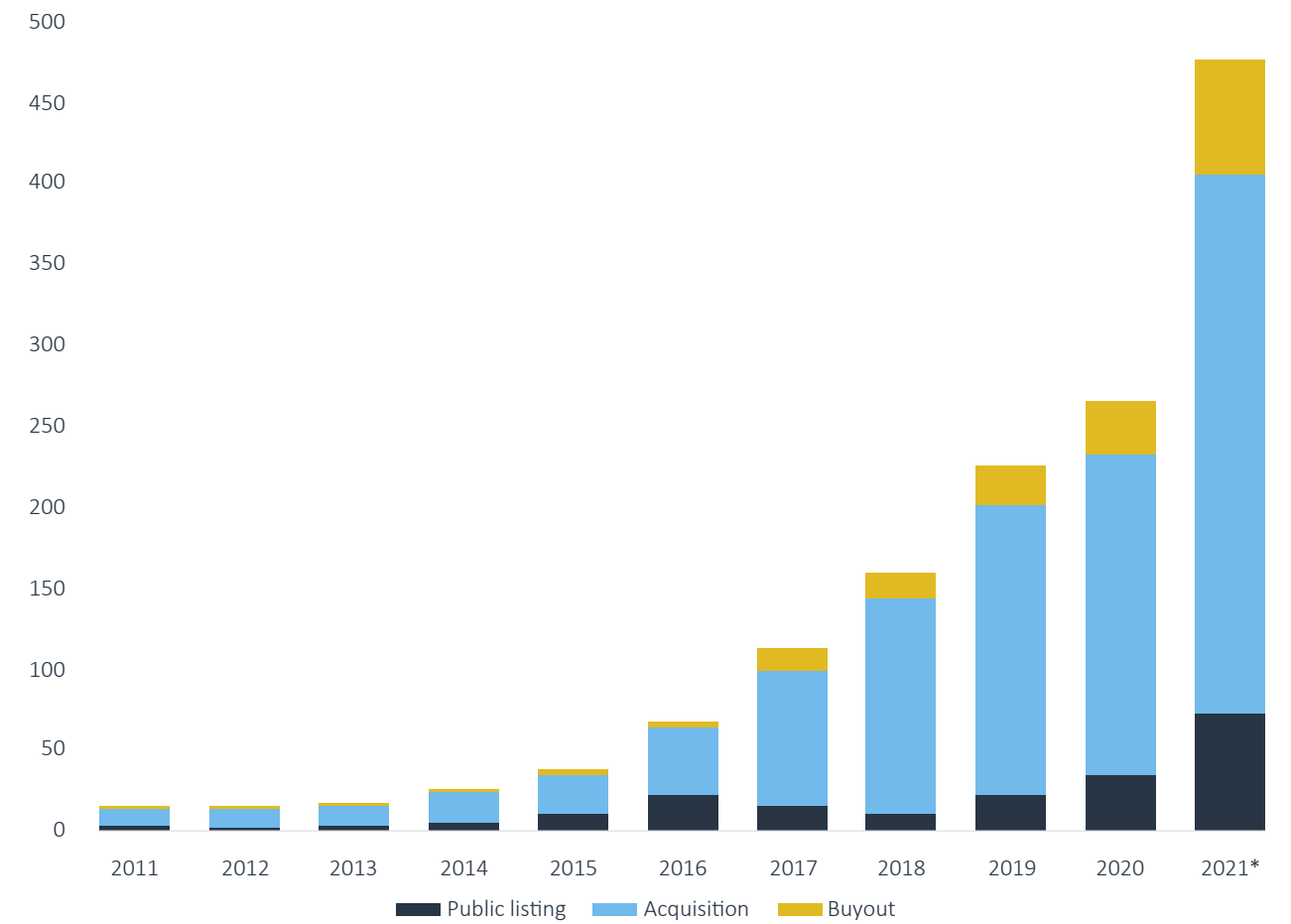
APPENDIX

Figure 36. AI & ML VC EXIT VALUE (\$B) BY TYPE



Source: PitchBook | Geography: Global | *As of December 31, 2021

Figure 37. AI & ML VC EXIT COUNT BY TYPE



Source: PitchBook | Geography: Global | *As of December 31, 2021



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