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Methods and systems for model management

Abstract

Methods, systems, and platforms for managing machine learning models are described. A model registry system receives first data including a model and second data including metadata and at least one metric of the model. Via a local network, the first data is stored to a data storage device and the second data is sent to an application programming interface (API). The first data is retrieved from the data storage device to a model use case program operating in a software development environment native to where the model registry system stores the model. The second data, including the metadata and the at least one metric of the model, is sent to a user interface (UI) via the API. The stored model can be deployed from the model use case program via the API.

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Background/Summary

TECHNICAL FIELD

(1) The present application relates generally to computer data science, and in particular to methods and systems for managing machine learning models.

BACKGROUND

(2) Machine learning applications have become widely adopted in various domains including data science as applied in retail enterprises. Machine learning models are key components that enable these machine learning applications. The life cycle of a machine learning model starts with data

processing, going through feature engineering, model experimentation, deployment, and maintenance. Model management systems are needed to store, track, manage, and benchmark machine learning models, to ensure effective and efficient applications.

(3) Although the importance of model management systems is generally recognized, there are many challenges in designing and implementing such systems. A large-scale enterprise may utilize many different machine learning models, including very similar models at different points in time, or for similar use cases. Accordingly, machine learning models are often placed in different environments and frameworks across an enterprise through the phases of the machine learning life cycle.

Multiple users will access the models being managed and each of them may have different development framework. Thus, it can be difficult to easily identify a particular machine learning model that may fit a need or use case, since many models may be deployed in a splintered fashion within an enterprise network.

(4) In view of the above and other challenges, improvements are desirable.

SUMMARY

(5) In general, this patent document relates to a software service usable to provide a repository with easy access to previously trained machine learning models. A development team that utilizes machine learning models can include multiple users working with various types of software development environments. Machine learning models are trained with input data by some of the users at one time, and are used for inferences by the same or other users at another time.

Additionally, machine learning models that can be accessed by the development team can be in different phases of a model's life cycle. The models can have different metrics, too. More specifically, this document relates to methods and systems for sharing machine learning models as well as their metadata and metrics across different users in various development environments to increase reusability and cut down retraining time. Also, the disclosed methods and systems fit machine learning model management into the user's native workflow to improve productivity, and save network capacity resources by managing models in an offline mode.

(6) In a first aspect, methods for managing machine learning models are disclosed. An example method includes receiving, by a model registry system, first data including a model and second data including metadata and at least one metric of the model, the model having been trained in a model training system connected to the model registry system via a local network. The example method also includes storing, by the model registry system and via the local network, the first data including the model in a data storage device, the data storage device operated by a first database management system; and sending, by the model registry system and via the local network, the second data including the metadata and the at least one metric of the model to an application programming interface (API). The example method further includes retrieving, by the model registry system and using the first database management system, the first data including the model from the data storage device to a model use case program, both the first database management system and the model use case program operating in a software development environment; and sending, via the API, the second data including the metadata and the at least one metric of the model to a user interface (UI).

(7) In a second aspect, systems for managing machine learning models are disclosed. An example system includes an input device, a memory device, a processing device in communication with the memory device, and an output device. The processing device is configured to receive, from the input device, first data including a model and second data including metadata and at least one metric of the model, the model having been trained in a model training system connected to the system via a local network. The processing device is also configured to store, via the output device and the local network, the first data including the model in a data storage device, the data storage device operated by a first database management system; and send, via the output device and the local network, the second data including the metadata and the at least one metric of the model to an application programming interface (API). The processing device is further configured to retrieve,

using the first database management system, the first data including the model from the data storage device; send the first data including the model to a model use case program, both the first database management system and the model use case program operating in a software development environment; and send, via the API, the second data including the metadata and the at least one metric of the model to a user interface (UI).

(8) In a third aspect, platforms for managing machine learning models are disclosed. An example platform includes a first computing device and a second computing device, a plurality of data storage devices, a network server device, and a local network in communication with the plurality of data storage devices, the network server device, the first computing device, and the second computing device. The first computing device is configured to receive, via the local network, first data including a model and second data including metadata and at least one metric of the model, the model having been trained using the second computing device. The first computing device is also configured to store, via the local network, the first data including the model in the plurality of data storage devices, the plurality of data storage devices operated by at least one database management system; and send, via the local network, the second data including the metadata and the at least one metric of the model to an application programming interface (API) operating on the network server device. The first computing device is further configured to retrieve, using the at least one database management system, the first data including the model from the plurality of data storage devices; send the first data including the model to a model use case program operating on the second computing device, both the at least one database management system and the model use case program operating in a software development environment; and send, via the API, the second data including the metadata and the at least one metric of the model to a user interface (UI) operating on the second computing device.

(9) Other objects and advantages of the invention will be apparent to one of ordinary skill in the art upon reviewing the detailed description of the invention.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The following drawings are illustrative of particular embodiments of the present disclosure and therefore do not limit the scope of the present disclosure. The drawings are not to scale and are intended for use in conjunction with the explanations in the following detailed description. Embodiments of the present disclosure will hereinafter be described in conjunction with the appended drawings, wherein like numerals denote like elements.

(2) FIG. 1 is a schematic diagram illustrating an example system utilizing machine learning models.

(3) FIG. 2 is a schematic block diagram illustrating an example system for managing machine learning models.

(4) FIG. 3 is a system flow diagram illustrating an example system and processes for managing machine learning models.

(5) FIG. 4 is a flow chart illustrating an example method for managing machine learning models.

(6) FIG. 5 is a flow chart illustrating another example method for managing machine learning models.

(7) FIG. 6 is a layout diagram illustrating an example user interface for viewing metrics of machine learning models.

(8) FIG. 7 is a layout diagram illustrating another example user interface for viewing metadata and metrics of machine learning models.

(9) FIG. 8 illustrates an example computing system on which aspects of the present disclosure may be implemented.

(10) Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate embodiments of the invention, and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION

(11) Various embodiments will be described in detail with reference to the drawings, wherein like reference numerals represent like parts and assemblies throughout the several views. Reference to various embodiments does not limit the scope of the claims attached hereto. Additionally, any examples set forth in this specification are not intended to be limiting and merely set forth some of the many possible embodiments for the appended claims.

(12) For purposes of this patent document, the terms “or” and “and” shall mean “and/or” unless stated otherwise or clearly intended otherwise by the context of their use. Whenever appropriate, terms used in the singular also will include the plural and vice versa. The use of “a” herein means “one or more” unless stated otherwise or where the use of “one or more” is clearly inappropriate. The use of “or” means “and/or” unless stated otherwise. The use of “comprise,” “comprises,” “comprising,” “include,” “includes,” “including,” “having,” and “has” are interchangeable and not intended to be limiting. The term “such as” also is not intended to be limiting. For example, the term “including” shall mean “including, but not limited to.”

(13) All ranges provided herein include the upper and lower values of the range unless explicitly noted. Although values are disclosed herein when disclosing certain exemplary embodiments, other embodiments within the scope of the pending claims can have values other than the specific values disclosed herein or values that are outside the ranges disclosed herein.

(14) Terms such as “substantially” or “about” when used with values or structural elements provide a tolerance that is ordinarily found during testing and production due to variations and inexact tolerances in factor such as material and equipment.

(15) Generally speaking, the present disclosure relates to systems and methods for managing machine learning models by storing the source code, description, versioning, input data location, and other metadata or metrics of the managed models. In particular, the present disclosure relates to storing machine learning models in a repository with access shared by multiple users that can be using different software development environments or implementing different hardware structure to train machine learning models. Without a managed model repository providing a simple mechanism to share across teams of machine learning users, there could be problems. For example, when a user wants to use a previously trained model, the model must be trained again with the previous input data. Besides extra costs of retraining, the input dataset would likely have changed by that time. With the disclosed systems, a user can train machine learning models in an accustomed development environment while another user can apply these models for inferences at a later different time without having to retrain them. By providing seamless integration of the training and the application of machine learning models, the systems and methods described herein increase reusability of models and improve user productivity.

(16) In example implementations, the model management systems described herein store machine learning models in a flexible structure of various types of data storage devices via a local network. For instance, the systems and methods described herein support container-based data storage device which is suitable for CPU-based training of machine learning models as well as distributed data storage device which is suitable for GPU-based training. As a result, more comprehensive integration of various development environments is achieved. Furthermore, it provides a more flexible set of use cases that can benefit technically from the model management systems described herein.

(17) In another embodiment, the model management systems and methods described herein stores models in native development environments in which they will be applied for inferences. Thus, models are executable instantly upon retrieval, and users can weave this step into their production workflows without introducing any additional delays. As a result, the productivity of developers

using the disclosed model management systems is further improved.

(18) Still further, it can be non-advantageous to require interconnection of systems responsible for the training, the storage, and the application of machine learning models via the Internet because any integrated workflow would then necessarily incur function calls over Internet. These function calls over the Internet can be expensive in terms of consumption of network capacity resources. When a development system of hardware and software involving machine learning models scales up, the extra costs of consuming network capacity resources can quickly add up not only in terms of equipment costs but also in terms of the overall efficiency of the development system. Therefore, further embodiments of the subject matter described herein supports offline model management to reduce consumption of network resources by only using local networks.

(19) Referring first to FIG. 1, an example machine learning system **100** in which aspects of the present disclosure may be implemented is shown. The machine learning system **100** includes at least one computing station **104**, a computing system **120**, and a communication system **114**. The communication system **114** is configured to receive and send data communications in between the computing station **104** and the computing system **120**. The computing station **104** is configured to send, via the communication system **114**, data including or identifying trained machine learning models to the computing system **120** for storing the models. The computing system **120** is configured to store the machine learning models. The computing system **120** is also configured to send, via the communication system **114**, data describing, or including, the stored machine learning models to the computing station **104** upon model retrieval by the computing station **104**. Users (sometimes also referred to as machine learning engineers) **90** and **92** are also shown in FIG. 1.

(20) In some embodiments, the system **100** includes multiple computing stations **104** operated by multiple users, respectively. The computing system **120** is configured to store machine learning models received from one of the computing stations **104** via the communication system **114**. The computing system **120** is also configured to send the stored machine learning models to another one of the computing stations **104** via the communication system **114** upon model retrieval.

(21) The computing station **104** includes a computer software **106**, which is configured to operate on the computing station **104**. The computer software **106** includes a machine learning application **108** and a user interface **112**. Machine learning engineers or users must train machine learning models with input data before they can implement the models to draw inferences. For instance, the user **90** uses the machine learning application **108**, which operates on the computing station **104**, to develop computer software involving machine learning models. In various examples, the machine learning application **108** can include software programs configured to train machine learning models with input data, software programs configured to implement machine learning models for drawing inferences, or both types of software programs. The user interface **112** is another software program which is configured to display viewable contents to its users. The user interface **112** is also configured to take inputs from its users. For instance, the user **90** views data about machine learning models that has been visualized for display via the user interface **112**. Also, the user **90** inputs commands that affect the use of machine learning models via the user interface **112**.

(22) The computing system **120** includes at least one processing device **122** and at least one memory device **124**. In some embodiments, the at least one processing device **122** comprises one or more central processing units (CPU). In other embodiments, the at least one processing device **122** additionally or alternatively includes one or more digital signal processors, field-programmable gate arrays, or other electronic circuits.

(23) The at least one memory device **124** operates to store data and instructions. In some embodiments, the at least one memory device **124** stores instructions for the at least one processing device **122** to execute on the computing system **120**. The least one memory device **124** includes at least some form of computer-readable medium. Computer readable medium includes any available medium that can be accessed by the at least one processing device **122**. By way of example, computer-readable medium includes computer readable storage medium and computer readable

communication medium.

(24) Computer readable storage medium includes volatile and nonvolatile, removable and non-removable medium implemented in any device configured to store information such as computer readable instructions, data structures, program modules, or other data. Computer readable storage medium includes, but is not limited to, random access memory, read only memory, electrically erasable programmable read only memory, flash memory and other memory technology, compact disc read only memory, blue ray discs, digital versatile discs or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to store the desired information and that can be accessed by the at least one processing device **122**. In some embodiments, computer readable storage medium is non-transitory computer readable storage medium.

(25) Computer readable communication medium embodies computer readable instructions, data structures, program modules or other data in a modulated data signal such as a carrier wave or other transport mechanism and includes any information delivery medium. The term “modulated data signal” refers to a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, computer readable communication medium includes wired medium such as a wired network or direct-wired connection, and wireless medium such as acoustic, radio frequency, infrared, and other wireless medium. Combinations of any of the above are also included within the scope of computer readable medium.

(26) In the example illustrated by FIG. **1**, the at least one memory device **124** stores computer readable instructions, data structures, program modules, or other data of a model registry **102**. When the at least one processing device **122** of the computing system **120** executes computer readable instructions of the model registry **102**, the computing system **120** operates as a model registry system (sometimes also referred to as a model management system, a model storage system, and the like). In an example implementation, the model registry **102** operating on the computing system **120** is configured to store the source code, description, versioning, input data location, and other metadata or annotated information of machine learning models in the at least one memory device **124**. By using the model registry **102** to store the source code, description, versioning, input data location, and other metadata or annotated information of machine learning models, a managed model repository is created providing a simple mechanism to share across teams of machine learning engineers. The model registry **102** solves the problem that, for example, when a machine learning engineer wants to use a previously trained model, the model must be trained again with the previous input data. Besides saving the extra costs of retraining the machine learning model, the model registry **102** resolves the issue that input dataset used to train the model would likely have changed by the time of using the model. Because the machine learning engineer can identify and retrieve the desired model according to the stored metadata describing the model and the machine learning engineer does not have to retrain the model with input data.

(27) In another example implementation, the model registry **102** operating on the computing system **120** is configured to store the source code, description, versioning, input data location, and other metadata or annotated information of machine learning models in other data storage devices that are connected to the computing system **120** via the communication system **114**.

(28) In yet another example implementation, the computing system **120** is a distributed computing environment comprising at least one network server, multiple computing devices, and multiple memory devices. The network server is configured to be in communication with other components of the distributed computing environment. The functionalities of the model registry **102** can be configured to be operated and executed on any combination of the multiple computing devices and memory devices. The functionalities of the model registry **102** can be configured to be operated and executed in a number of different sequential or parallel orders.

(29) The communication system **114** is configured to transmit data of machine learning models managed by the model registry **102** between the computing station **104** and the computing system

120. The communication system **114** can be implemented as an Ethernet network, a token-ring network, a fiber optic network, a wireless network (e.g., Wi-Fi), or another type of network.

(30) In some embodiments, the communication system **114** is a local network that is capable of offline functionalities without having to access the Internet. Examples of a local work includes local area network (LAN), wireless local area network (WLAN), etc. In other embodiments, the communication system **114** is a local connection interface configured to send and receive data communications in an offline mode without having to access any network. When systems on which a software program is operating are connected over the Internet, software function calls over Internet are expensive in terms of consumption of network capacity resources. When a development system of hardware and software involving machine learning models scales up, the extra costs of consuming network capacity resources can quickly add up not only in terms of equipment costs but also in terms of the overall efficiency of the development system. Therefore, the communication system **114** supporting offline model management reduces consumption of network resources by only using local networks or local connections.

(31) FIG. 2 illustrates an example system **200** for managing machine learning models through their model lifecycles from training models to inferencing by using models. The example system **200** includes the model registry **102**, the user interface **112** (illustrated and described in FIG. 1), a machine learning training system **212**, a machine learning inferencing system **214**, a security layer **222**, and a data storage device **224**.

(32) The machine learning training system **212** is configured to prepare input data for training machine learning models by obtaining training data and test data that is used to develop a machine learning model. The machine learning training system **212** is also configured to conduct feature engineering by identifying or creating the appropriate descriptors from the input data (i.e., features) to be used by the machine learning model. The machine learning training system **212** is further configured to train machine learning models using the input data.

(33) In some embodiments, the machine learning training system **212** is also configured to experiment with different machine learning models on the training and test data. For instance, since the key requirement when the machine learning training system **212** experiments with different machine learning models is to enable the users to choose the best model, metadata captured in this phase of experimentation includes items such as performance metrics for the model, hyperparameter values used during training, lifecycle indicators of the model, etc.

(34) After training the machine learning model, the machine learning training system **212** is then configured to send data of the trained model and the captured metadata about the trained model to the model registry **102** operating on, for example, the computing system **120** (illustrated and described in FIG. 1). In some embodiments, users of the model registry **102** identify and retrieve the desired model base on the stored metadata capturing and describing the model. In other embodiments, users of the model registry **102** retrieve the data of the model itself.

(35) In the example illustrated by FIG. 2, the model registry **102** includes a model manager **202**, a library implementation tool **204**, an ensembled models implementation tool **206**, a custom model implementation tool **208**, and a model data transfer layer **210**. The model manager **202** is configured to control model management functionalities of the model registry **102**. The model manager **202** is configured to call on the library implementation tool **204**, the ensembled models implementation tool **206**, or the custom model implementation tool **208**, depending on the characters of the machine learning model being managed by the model registry **102**.

(36) In some embodiments, the machine learning model being managed by the model registry **102** is of a type of standard library model. A standard library model is a machine learning model that is in accordance with a standard definition of format. The model manager **202** is configured to process the storage, the management, and the retrieval of the standard library model using the library implementation tool **204**.

(37) In other embodiments, the machine learning model being managed by the model registry **102**

is of a type of ensembled models. A set of ensembled models is a set of machine learning models that are combined according to certain rules. The model manager **202** is configured to process the storage, the management, and the retrieval of the ensembled models using the ensembled models implementation tool **206**.

(38) In further embodiments, the machine learning model being managed by the model registry **102** is of a type of custom model. A custom model is a machine learning model that is customized according to a specific design. The model manager **202** is configured to process the storage, the management, and the retrieval of the custom model using the custom model implementation tool **208**.

(39) The model data transfer layer **210** is configured to be the interface between the model registry **102** and systems external to the model registry **102** (e.g., the data storage device **224**). The model manager **202** is configured to control the model data transfer layer **210** to transfer data of the machine learning model being managed by the model registry **102**, thereby sending the data of the machine learning model to the data storage device **224**, which stores the data of the machine learning model being managed by the model registry **102**. In some embodiments, the data storage device **224** stores the data of the model using a database management system operating on the data storage device **224**.

(40) In some embodiments, the model registry **102** is configured to send data of the machine learning model through the security layer **222**. The security layer **222** maintains a certain level of data security for the data transmission between the model registry **102** and the data storage device **224**.

(41) The model manager **202** is also configured to send metadata and metrics about the machine learning model being managed by the model registry **102** to the user interface **112**. The user interface **112** includes a machine learning lifecycle indicator **216**, a custom metrics visualization tool **218**, and a model performance indicator **220**.

(42) The machine learning lifecycle indicator **216** is configured to display an indicator that indicates the current lifecycle phase of the machine learning model being managed by the model registry **102**. For instance, the lifecycle of a machine learning model can be divided into five phases, namely: (1) data preparation, that is obtaining the training and test data to develop a model; (2) feature engineering, that is identifying or creating the appropriate descriptors from the input data (i.e., features) to be used by the model; (3) model training and experimentation, that is experimenting with different models on the training and test data and choosing the best; (4) deployment, that is deploying the chosen model in an inferencing system; and (5) maintenance, that is monitoring the model performance, updating the model as needed, and eventually retiring the model.

(43) The custom metrics visualization tool **218** is configured to visualize at least one customarily designed metric about the machine learning model being managed by the model registry **102**. For example, the user that stores or registers a machine learning model using the model registry **102** can also use the custom metrics visualization tool **218** to visualize information about feature importance of the model. In this case, the custom metrics visualization tool **218** is configured to display the visualized information about feature importance of the model to other users via the user interface **112**.

(44) The model performance indicator **220** is configured to display performance ratings of the machine learning model being managed by the model registry **102** to users who are reviewing the model via the user interface **112**. Examples of the performance ratings including a minimum accuracy rating, a maximum accuracy rating, and the number of user teams that are using the model, etc.

(45) Besides the machine learning lifecycle indicator **216**, the custom metrics visualization tool **218**, and the model performance indicator **220**, the user interface **112** is also configured to display, to reviewing users, other metadata about the machine learning model being managed by the model

registry **102**. For example, the user interface **112** displays the name, the description, the creator's name, the code location, and the data location of the model. In other examples, the user interface **112** displays the number of models that are grouped under a common project.

(46) The machine learning inferencing system **214** is configured to implement trained machine learning models in applications to draw inferences. The machine learning inferencing system **214** includes software programs configured to apply trained machine learning models. For example, the machine learning inferencing system **214** includes a model use case program configured to apply the model to an actionable use case. If a model is suitable for the user's implementation goal, the user can avoid retraining and easily start inferencing with one or two lines of code using the model use case program. Because the model use case program operates in the same native software development environment as the model registry **102**.

(47) In the example illustrated by FIG. 2, the machine learning inferencing system **214** communicates with the model registry **102** when the machine learning inferencing system **214** requests to use one of the models managed by the model registry **102**. Upon receiving and approving the request, the model registry **102** is configured to retrieve data of the model from the data storage device **224** by controlling the data storage device **224**. Upon retrieval of the data of the model, the model registry **102** is configured to send the data of the model to the machine learning inferencing system **214**.

(48) In some embodiments, the model registry **102**, when retrieving the machine learning model, controls the data storage device **224** through a database management system operating on the data storage device **224**.

(49) In other embodiments, the model registry **102** is configured to control the data storage device **224** to directly send the machine learning model to the machine learning inferencing system **214**.

(50) FIG. 3 illustrates an example system **300** and example processes operating on the system **300** for managing machine learning models. In the example illustrated by FIG. 3, the system **300** includes the model registry **102**, a container model training system **304**, a container data storage device **306**, a container model use case program **308**, a model management application programming interface (API) **310**, a user interface **312**, a relational database management system **314**, a distributed model training system **324**, a distributed data storage device **326**, and a distributed model use case program **328**.

(51) Example processes operating on the system **300** include steps **404**, **406**, **408**, **410**, **414**, **504**, **506**, and **510**. In some examples, steps **402**, **412**, **416**, **502**, and **512** are further included. These steps are described with details below and in FIGS. 4-5.

(52) In some embodiments, the system **300** further includes a software development environment **302**. The software development environment **302** is configured to develop a machine learning model and send the model to a model training system. In some examples, the software development environment **302** sends the model to the container model training system **304**, which trains the model in step **402**. In other examples, the software development environment **302** sends the model to the distributed model training system **324**, which trains the model in step **502**. In further examples, the software development environment **302** sends the model to both the container model training system **304** and the distributed model training system **324**.

(53) The container model training system **304** is based on a container technology, which enables software programs to operate in compatibility with a variety of different computing environments (e.g., WINDOWS or LINUX). The container technology is a form of operating system virtualization. A single container can be used to run anything from a small microservice or software process to a larger application. Inside a container are all the necessary executable files, binary code, libraries, and configuration files. Compared to server or machine virtualization approaches, however, containers do not contain operating system images. This makes them more lightweight and portable, with significantly less overhead. In larger application deployments, multiple containers can be deployed as one or more container clusters. For instance, the container

technology utilized by the container model training system **304** is suitable for CPU-based training of machine learning models.

(54) In some embodiments, the model registry **102** is configured to receive data including the machine learning model from the container model training system **304** in step **404**. The model registry **102** is also configured to store the data including the machine learning model in the container data storage device **306** in step **406**. The container data storage device **306** is also based on the container technology and is operated by a database management system that processes the movement of the model data.

(55) The model registry **102** is further configured to send metadata and metrics of the model to the model management API **310** in step **408**. The model management API **310** provides an addressable interface between the model registry **102** and the other systems or computer applications, acting as an intermediary layer exposed by the model registry **102** that processes data transfer between systems with improved convenience of collaboration and added layer of data security.

(56) For model data retrieval, the model registry **102** is configured to control the container data storage device **306** through the database management system that processes the movement of the model data. By controlling the container data storage device **306**, the model registry **102** is configured to retrieve model data from the container data storage device **306** to the container model use case program **308** in step **410**. The container model use case program **308**, based also on the container technology, operates on the machine learning inferencing system **214** (illustrated and described in FIG. 2) to apply the model to an actionable use case for inferencing. In some examples, the container model use case program **308** operates in the same native software development environment as the database management system that processes the movement of the model data in the container data storage device **306**. Therefore, there is seamless integration between where the model data is stored and where the model is being applied. If a model is suitable for the user's implementation goal, the user can avoid retraining and easily start inferencing with one or two lines of code using the container model use case program **308**. With simple computer software statements to apply the model, the user can easily fit both the retrieval and the inference of the machine learning models into a software development flow that the user is accustomed to (e.g., with scripting computer languages). Hence, the productivity of the user is significantly increased.

(57) In some example implementations, the container model use case program **308** is also configured to deploy the retrieved machine learning model via the model management API **310** in step **412**. Sitting in a system external to where machine learning models are stored, the model management API **310** is used as an interface to pass in data required for running a machine learning application. The user can access a data link that is linked to the model management API **310** and thereby get outputs of the machine learning application through the model management API **310**. By deploying the model through the model management API **310**, the user of the model does not need to manage all the background processes involving the model. Therefore, the usability of the machine learning model is significantly improved.

(58) The model management API **310** is configured to send the metadata and metrics of the machine learning model, which the model management API **310** receives from the model registry **102**, to the user interface **312** in step **414**. The user interface **312** is then configured to display the metadata and metrics for the user to review.

(59) In some example implementations, the model management API **310** is further configured to send the metadata and metrics of the machine learning model, which the model management API **310** receives from the model registry **102**, to the relational database management system **314**. By storing the metadata and metrics of the machine learning model with the relational database management system **314**, more advanced operations on the metadata and metrics are enabled. For instance, the relational database management system **314** can be a POSTGRES database management system compatible with Structured Query Language (SQL). The relational database management system **314** is used for data analysis and creating reports related to the metadata and

metrics of the machine learning model.

(60) In other embodiments, the system **300** works with a distributed computing technology instead of the regular container technology in managing machine learning models. In this alternative scenario, the model registry **102** in the system **300** is configured to receive data including the machine learning model from the distributed model training system **324** in step **504**, instead of receiving from the container model training system **304** in step **404**. Also, the model registry **102** is configured to store the data including the machine learning model in the distributed data storage device **326** in step **506**, rather than storing in the container data storage device **306** in step **406**. Furthermore, the model registry **102** is configured to retrieve model data from the distributed data storage device **326** to the distributed model use case program **328** in step **510**, instead of retrieving from the container data storage device **306** to the container model use case program **308** in step **410**.

(61) In examples of deploying the model through the model management API **310**, the distributed model use case program **328** is configured to execute such deployment in step **512**.

(62) The distributed computing technology, by distributing the processing power to each of multiple nodes, clusters, or computing devices, significantly improves the processing speed of different computation tasks that need to be performed on large volumes of data. For instance, using the distributed computing technology on the distributed model training system **324**, the distributed data storage device **326**, and the distributed model use case program **328** is suitable for GPU-based training of machine learning models.

(63) While using the distributed computing technology for increased scalability, the model management processes on the system **300** have similar features as embodied by the descriptions above of the steps **404**, **406**, **408**, **410**, **412**, **414**, and **416**. For example, with simple computer software statements to apply the model in a native development environment, the user can easily fit both the retrieval and the inference of the machine learning models into a software development flow that the user is accustomed to (e.g., with scripting computer languages). Hence, the productivity of the user is significantly increased. Furthermore, by deploying the model through the model management API **310**, the user of the model does not need to manage all the background processes involving the model. Therefore, the usability of the machine learning model is significantly improved.

(64) In other embodiments, the system **300** is configured to execute model management processes based on both the container technology and the distributed computing technology for improved flexibility. For instance, the system **300** for model management is compatible with teams of machine learning engineers who adopt different computing environments. The system **300** is enabled to pick the best solution for machine learning models that are trained based on CPUs, and for those models that are trained based on GPUs.

(65) Data transmissions in steps of the model management processes in FIG. 3 are carried out in various types of data connections. In example implementations, data is transmitted via local connections in steps **404**, **406**, **408**, **410**, **412**, **504**, **506**, **510**, and **512**. Local connections to transmit the data can form a local network without connecting to the Internet or any other networks (e.g., public networks) external to the local network. By transmitting data over local connections or the local network, an offline mode of model management is enabled to reduce costs of network resources. The extra costs of consuming network resources can quickly add up not only in terms of equipment costs but also in terms of the overall efficiency of the development system utilizing machine learning models. Therefore, the offline mode of model management improves the efficiency of systems that manage and apply machine learning models.

(66) FIG. 4 illustrates an example method **400** for managing machine learning models based on a container-based technology. In some embodiments, the example method **400** is operated with the system **300** (illustrated and described in FIG. 3). In the illustrated example, the method **400** includes steps **402**, **404**, **406**, **408**, **410**, **412**, **414**, and **416**. In other examples, one or more of the

steps **402**, **412**, and **416** can be omitted.

(67) In the example shown, the method **400** includes training a model using a container model training system, the model having been developed using a software development environment (step **402**). Machine learning models must be trained with input data before they can be implemented by users to draw inferences. Training a model in the container model training system is suitable for CPU-based training. The software development environment used to develop the model and the software development environment for inference can be the same development environment. In other implementations, the software development environment used to develop the model is different from the software development environment for inference.

(68) The method **400** further includes receiving the model from the container model training system by a model registry (step **406**). Received data includes the source code, description, versioning, input data location, and other metadata or annotated information of the machine learning model. With received data, the model registry (e.g., the model registry **102**) provides a mechanism to share the access to machine learning models across teams of users and machine learning engineers. For instance, a first user created a machine learning model and modified the model without storing the initial version of the model. When a second user wants to use the initial model, the second user will have to retrain the model with input model without the model registry managing the model. Furthermore, the input data may have changed since the creation of the model, thereby makes retraining very difficult.

(69) With the example method **400**, the model registry is configured to solve the technical issues of the costs and difficulty involved with retraining. The example method **400** further includes storing the model in a container data storage device by the model registry (step **406**), and sending metadata and metrics of the model to a model management API by the model registry (step **408**). By storing the model in the container data storage device, the user who develops the model or another user can apply the model at a different time after the model is trained, without locating the initial input data and retraining the model with the input data. By reviewing the metadata and metrics of the model via the model management API, the user can compare and select machine learning models, based on the metadata and metrics, that are suitable for the user's implementation.

(70) For retrieval of the model, the example method **400** includes retrieving, from the container data storage, the model to a container model use case program (step **410**). In some examples, the container data storage is operated by a database management system that controls the data movement in and out from the container data storage. The user can apply the model in the same native software development environment as the database management system that processes the movement of the model data in the container data storage device. Using the same software development environment for the storage and the application of the model enables a complete and native workflow, which improves the productivity of the user.

(71) The example method **400** further includes deploying, from the container model use case program, the model via the model management API (step **412**). As described in FIG. 3, deploying through the model management API simplifies the process of applying the model from the perspective of the user who implements the model. Such deployment makes it technically easier to obtain outputs of the implementation of machine learning models.

(72) The example method **400** further includes sending the metadata and metrics of the model to a user interface via the model management API (step **414**), and sending the metadata and metrics of the model to a relational database management system via the model management API (step **416**). The metadata and metrics can be viewed by users interactively via the user interface. However, interactive display is not optimal when there is a very large volume of metadata and metrics to be analyzed. Rather, processing large volumes of metadata and metrics with the relational database management system is a technically superior solution for more advanced data analytics.

(73) FIG. 5 illustrates another example method **500** for managing machine learning models based on a distributed computing technology. In some embodiments, the example method **500** is operated

with the system **300** (illustrated and described in FIG. 3). In the illustrated example, the method **500** includes steps **408**, **414**, and **416** (illustrated and described in FIG. 4). The method **500** further includes steps **502**, **504**, **506**, **510**, and **512**. In other examples, one or more of the steps **502**, **512**, and **416** can be omitted.

(74) The method **500** shares the features as described for the method **400**. However, the method **500** is based on the distributed computing technology instead of the regular container-based technology used by the method **400**. Accordingly, the method **500** includes training a model using a distributed model training system, the model having been developed using a software development environment (step **502**); receiving the model from the distributed container model training system by a model registry (step **504**); storing, by the model registry, the model in a distributed data storage device (step **506**); retrieving, from the distributed data storage, the model to a distributed model use case program (step **510**); and deploying, from the distributed model use case program, the model via the model management API (step **512**).

(75) Using the distributed computing technology provides increased scalability and flexibility over different computing structures. For instance, the distributed model training system, the distributed data storage device, and the distributed model use case program are suitable for GPU-based training of machine learning models.

(76) FIG. 6 illustrate an example user interface **600** to display metadata and metrics of machine learning models. The user interface **600** includes a project indicator **602** configured to indicate the name of the project that the current model is grouped under. The user interface **600** also includes a model number indicator **604** configured to indicate the number of models that are grouped under the same project. The user interface **600** further includes a maximum accuracy indicator **606** and a minimum accuracy indicator **608** configured to indicate a range of accuracy for the current model defined by a lower-end accuracy score and a higher-end accuracy score.

(77) FIG. 7 illustrate another example user interface **700** to display metadata and metrics of machine learning models. The user interface **700** includes a model name field **702** indicating the name of the current model, a model description field **704** configured to describe the current model with textual information, a code location field **706** indicating where the source code of the current model is stored, and a data location field **708** indicating where the data used by the current model is stored. The user interface **700** also includes a custom metric chart **710**. For instance, the custom metric chart **710** can display information about feature importance of the current model. The user interface **700** further includes a standard metric card **712** configured to display standard metrics of the current model. Examples of standard metrics include the creator of the model, the number of teams using the current model, and the model's accuracy score band, etc.

(78) FIG. 8 illustrates an example system **800** with which disclosed systems and methods can be used. In an example, one or more such systems **800** may be used to implement the computing station **104** and the computing system **120** described above in conjunction with FIG. 1, and the machine learning training system **212** and the machine learning inferencing system **214** described above in conjunction with FIG. 2.

(79) In an example, the system **800** can include a computing environment **802**. The computing environment **802** can be a physical computing environment, a virtualized computing environment, or a combination thereof. The computing environment **802** can include memory **804**, a communication medium **812**, one or more processing units **814**, a network interface **816**, and an external component interface **818**.

(80) The memory **804** can include a computer readable storage medium. The computer storage medium can be a device or article of manufacture that stores data and/or computer-executable instructions. The memory **804** can include volatile and nonvolatile, transitory and non-transitory, removable and non-removable devices or articles of manufacture implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data. By way of example, and not limitation, computer storage medium

may include dynamic random access memory (DRAM), double data rate synchronous dynamic random access memory (DDR SDRAM), reduced latency DRAM, DDR2 SDRAM, DDR3 SDRAM, solid state memory, read-only memory (ROM), electrically-erasable programmable ROM, optical discs (e.g., CD-ROMs, DVDs, etc.), magnetic disks (e.g., hard disks, floppy disks, etc.), magnetic tapes, and other types of devices and/or articles of manufacture that store data.

(81) The memory **804** can store various types of data and software. For example, as illustrated, the memory **804** includes software application instructions **806**, one or more databases **808**, as well as other data **810**.

(82) The communication medium **812** can facilitate communication among the components of the computing environment **802**. In an example, the communication medium **812** can facilitate communication among the memory **804**, the one or more processing units **814**, the network interface **816**, and the external component interface **818**. The communications medium **812** can be implemented in a variety of ways, including but not limited to a PCI bus, a PCI express bus accelerated graphics port (AGP) bus, a serial Advanced Technology Attachment (ATA) interconnect, a parallel ATA interconnect, a Fiber Channel interconnect, a USB bus, a Small Computing system interface (SCSI) interface, or another type of communications medium.

(83) The one or more processing units **814** can include physical or virtual units that selectively execute software instructions, such as the software application instructions **806**. In an example, the one or more processing units **814** can be physical products comprising one or more integrated circuits. The one or more processing units **814** can be implemented as one or more processing cores. In another example, one or more processing units **814** are implemented as one or more separate microprocessors. In yet another example embodiment, the one or more processing units **814** can include an application-specific integrated circuit (ASIC) that provides specific functionality. In yet another example, the one or more processing units **814** provide specific functionality by using an ASIC and by executing computer-executable instructions.

(84) The network interface **816** enables the computing environment **802** to send and receive data from a communication network. The network interface **816** can be implemented as an Ethernet interface, a token-ring network interface, a fiber optic network interface, a wireless network interface (e.g., Wi-Fi), or another type of network interface.

(85) The external component interface **818** enables the computing environment **802** to communicate with external devices. For example, the external component interface **818** can be a USB interface, Thunderbolt interface, a Lightning interface, a serial port interface, a parallel port interface, a PS/2 interface, or another type of interface that enables the computing environment **802** to communicate with external devices. In various embodiments, the external component interface **818** enables the computing environment **802** to communicate with various external components, such as external storage devices, input devices, speakers, modems, media player docks, other computing devices, scanners, digital cameras, and fingerprint readers.

(86) Although illustrated as being components of a single computing environment **802**, the components of the computing environment **802** can be spread across multiple computing environments **802**. For example, one or more of instructions or data stored on the memory **804** may be stored partially or entirely in a separate computing environment **800** that is accessed over a network.

(87) Depending on the size and scale of the computing environment **802**, it may be advantageous to include one or more load balancers to balance traffic across multiple physical or virtual machine nodes. In an example, the node balancer may be a node balancer product provided by F5 NETWORKS, INC. of Seattle, Washington.

(88) Aspects of the platform **800** and the computing environment **802** can be protected using a robust security model. In an example, users may be made to sign into the system using a directory service, such as ACTIVE DIRECTORY by MICROSOFT CORPORATION of Redmond, Washington. Connection and credential information can be externalized from jobs using an

application programming interface. Credentials can be stored in an encrypted repository in a secured operational data store database space. Privileges can be assigned based on a collaboration team and mapped to a Lightweight Directory Access Protocol (LDAP) Group membership. A self-service security model can be used to allow owners to assign others permissions on their objects (e.g., actions).

(89) Each node may be configured to be capable of running the full platform **800**, such that portal can run and schedule jobs and serve the portal user interface as long as a single node remains functional. The environment **802** may include monitoring technology to determine when a node is not functioning so an appropriate action can be taken.

(90) Referring to FIGS. **1-8** generally, and according to some examples, methods for managing machine learning models are disclosed. An example method includes receiving, by a model registry system, first data including a model and second data including metadata and at least one metric of the model, the model having been trained in a model training system connected to the model registry system via a local network. The example method also includes storing, by the model registry system and via the local network, the first data including the model in a data storage device, the data storage device operated by a first database management system; and sending, by the model registry system and via the local network, the second data including the metadata and the at least one metric of the model to an application programming interface (API). The example method further includes retrieving, by the model registry system and using the first database management system, the first data including the model from the data storage device to a model use case program, both the first database management system and the model use case program operating in a software development environment; and sending, via the API, the second data including the metadata and the at least one metric of the model to a user interface (UI).

(91) Another example method further includes deploying, from the model use case program, the model via the API.

(92) Yet another example method further includes sending, via the API, the second data including the metadata and the at least one metric of the model to a second database management system.

(93) In some examples, the data storage device is a container data storage device and the model use case program is a container model use case program, the container data storage device and the container model use case program configured to operate in a plurality of computing environments.

(94) In other examples, the data storage device is a distributed data storage device and the model use case program is a distributed model use case program, the distributed data storage device and the distributed model use case program configured to operate on a plurality of computing devices.

(95) In further examples, storing the first data including the model in a data storage device comprises sending the first data via a security layer, the security layer configured to maintain a data security level of the first data.

(96) In yet further examples, the method further includes managing, using a model manager of the model registry system, the model, the model manager having a library implementation tool configured to manage a standard model, a custom models implementation tool configured to manage a custom model, and an ensembled models implementation tool configured to manage a combination of a plurality of models.

(97) In other examples, the metadata includes a first indicator indicating a lifecycle status of the model, and the at least one metric includes a second indicator indicating a performance level of the model.

(98) According to some examples, systems for managing machine learning models are described. An example system includes an input device, a memory device, a processing device in communication with the memory device, and an output device. The processing device is configured to receive, from the input device, first data including a model and second data including metadata and at least one metric of the model, the model having been trained in a model training system connected to the system via a local network. The processing device is also configured to store, via

the output device and the local network, the first data including the model in a data storage device, the data storage device operated by a first database management system; and send, via the output device and the local network, the second data including the metadata and the at least one metric of the model to an application programming interface (API). The processing device is further configured to retrieve, using the first database management system, the first data including the model from the data storage device; send the first data including the model to a model use case program, both the first database management system and the model use case program operating in a software development environment; and send, via the API, the second data including the metadata and the at least one metric of the model to a user interface (UI).

(99) In other examples, the processing device is further configured to deploy, from the model use case program, the model via the API.

(100) In further examples, the processing device is further configured to send, via the API, the second data including the metadata and the at least one metric of the model to a second database management system.

(101) In yet further examples, the data storage device is a container data storage device and the model use case program is a container model use case program, the container data storage device and the container model use case program configured to operate in a plurality of computing environments.

(102) In other examples, the data storage device is a distributed data storage device and the model use case program is a distributed model use case program, the distributed data storage device and the distributed model use case program configured to operate on a plurality of computing devices.

(103) In further example systems, storing the first data including the model in a data storage device comprises sending the first data via a security layer, the security layer configured to maintain a data security level of the first data.

(104) In other examples, the processing device is further configured to execute a plurality of model management instructions stored in the memory device, the plurality of model management instructions including a library implementation tool configured to manage a standard model, a custom models implementation tool configured to manage a custom model, and an ensembled models implementation tool configured to manage a combination of a plurality of models.

(105) In further example systems, communicating via the local network does not require communication via a public network.

(106) According to some examples, platforms for managing machine learning models are described. An example platform includes a first computing device and a second computing device, a plurality of data storage devices, a network server device, and a local network in communication with the plurality of data storage devices, the network server device, the first computing device, and the second computing device. The first computing device is configured to receive, via the local network, first data including a model and second data including metadata and at least one metric of the model, the model having been trained using the second computing device. The first computing device is also configured to store, via the local network, the first data including the model in the plurality of data storage devices, the plurality of data storage devices operated by at least one database management system; and send, via the local network, the second data including the metadata and the at least one metric of the model to an application programming interface (API) operating on the network server device. The first computing device is further configured to retrieve, using the at least one database management system, the first data including the model from the plurality of data storage devices; send the first data including the model to a model use case program operating on the second computing device, both the at least one database management system and the model use case program operating in a software development environment; and send, via the API, the second data including the metadata and the at least one metric of the model to a user interface (UI) operating on the second computing device.

(107) In other examples, the platform further includes a third computing device connected to the

local network, wherein the first computing device is further configured to deploy, from the model use case program operating on the second computing device, the model via the API and to the third computing device.

(108) In further examples, the plurality of data storage devices include a container data storage device configured to operate in a plurality of computing environments, and a distributed data storage device configured to operate on a plurality of computing devices.

(109) In yet further examples, the platform further includes a fourth computing device connected to the local network, wherein storing the first data including the model in the plurality of data storage devices comprises sending the first data via a security layer operating on the fourth computing device, the security layer configured to maintain a data security level of the first data.

(110) The above specification, examples and data provide a complete description of the manufacture and use of the composition of the invention. Since many embodiments of the invention can be made without departing from the spirit and scope of the invention, the invention resides in the claims hereinafter appended.

(111) Although the present disclosure and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the disclosure as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods, and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the present invention, disclosure, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present disclosure. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

Claims

1. A method comprising: receiving, by a model registry system, first data and second data, wherein the first data includes a model and the second data includes metadata and at least one custom metric of the model, the metadata including a first indicator indicating a lifecycle status of the model, and the at least one metric includes a second indicator indicating a performance level of the model, the model having been trained in a model training system connected to the model registry system via a local network, wherein the local network is a local connection interface configured to send and receive data communications in an offline mode; storing, by the model registry system and via the local network, the first data in a data storage device, the data storage device operated by a first database management system; sending, by the model registry system and via the local network, the second data to an application programming interface (API) configured to send the second data to a user interface (UI); retrieving, by the model registry system and using the first database management system, the first data from the data storage device to a model use case program, both the first database management system and the model use case program operating in a software development environment; and sending, via the API, the second data to the UI, wherein the UI is configured to display the at least one custom metric, wherein the at least one custom metric includes information about feature importance of the model.
2. The method of claim 1, further comprising deploying, from the model use case program, the model via the API.
3. The method of claim 1, further comprising sending, via the API, the second data to a second database management system.
4. The method of claim 1, wherein the data storage device is a container data storage device and the

model use case program is a container model use case program, the container data storage device and the container model use case program configured to operate in a plurality of computing environments.

5. The method of claim 1, wherein the data storage device is a distributed data storage device and the model use case program is a distributed model use case program, the distributed data storage device and the distributed model use case program configured to operate on a plurality of computing devices.

6. The method of claim 1, wherein storing the first data in a data storage device comprises sending the first data via a security layer, the security layer configured to maintain a data security level of the first data.

7. The method of claim 1, further comprising managing, using a model manager of the model registry system, the model, the model manager having a library implementation tool configured to manage a standard model, a custom models implementation tool configured to manage a custom model, and an ensembled models implementation tool configured to manage a combination of a plurality of models.

8. A system comprising: an input device; a memory device; a processing device coupled to the memory device; and an output device, wherein the processing device is configured to: receive, from the input device, first data and second data, wherein the first data includes a model and the second data includes metadata and at least one custom metric of the model, the metadata including a first indicator indicating a lifecycle status of the model, and the at least one metric includes a second indicator indicating a performance level of the model, the model having been trained in a model training system connected to the system via a local network, wherein the local network is a local connection interface configured to send and receive data communications in an offline mode; store, via the output device and the local network, the first data in a data storage device, the data storage device operated by a first database management system; send, via the output device and the local network, the second data to an application programming interface (API) configured to send the second data to a user interface (UI); retrieve, using the first database management system, the first data from the data storage device; send the first data to a model use case program, both the first database management system and the model use case program operating in a software development environment; and send, via the API, the second data to the UI, wherein the UI is configured to display the at least one custom metric, wherein the at least one custom metric includes information about feature importance of the model.

9. The system of claim 8, the processing device further configured to deploy, from the model use case program, the model via the API.

10. The system of claim 8, the processing device further configured to send, via the API, the second data to a second database management system.

11. The system of claim 8, wherein the data storage device is a container data storage device and the model use case program is a container model use case program, the container data storage device and the container model use case program configured to operate in a plurality of computing environments.

12. The system of claim 8, wherein the data storage device is a distributed data storage device and the model use case program is a distributed model use case program, the distributed data storage device and the distributed model use case program configured to operate on a plurality of computing devices.

13. The system of claim 8, wherein storing the first data in a data storage device comprises sending the first data via a security layer, the security layer configured to maintain a data security level of the first data.

14. The system of claim 8, the processing device further configured to execute a plurality of model management instructions stored in the memory device, the plurality of model management instructions including a library implementation tool configured to manage a standard model, a

custom models implementation tool configured to manage a custom model, and an ensembled models implementation tool configured to manage a combination of a plurality of models.

15. The system of claim 8, wherein communicating via the local network does not require communication via a public network.

16. A platform for model management, comprising: a first computing device and a second computing device; a plurality of data storage devices; a network server device; and a local network in communication with the plurality of data storage devices, the network server device, the first computing device, and the second computing device, wherein the local network is a local connection interface configured to send and receive data communications in an offline mode; wherein the first computing device is configured to: receive, via the local network, first data and second data, wherein the first data includes a model and the second data includes metadata and at least one custom metric of the model, the metadata including a first indicator indicating a lifecycle status of the model, and the at least one metric includes a second indicator indicating a performance level of the model, the model having been trained using the second computing device; store, via the local network, the first data in the plurality of data storage devices, the plurality of data storage devices operated by at least one database management system; send, via the local network, the second data to an application programming interface (API) operating on the network server device, the API being configured to send the second data to a user interface (UI) operating on the second computing device; retrieve, using the at least one database management system, the first data from the plurality of data storage devices; send the first data to a model use case program operating on the second computing device, both the at least one database management system and the model use case program operating in a software development environment; and send, via the API, the second data to the UI, wherein the UI is configured to display the at least one custom metric, wherein the at least one custom metric includes information about feature importance of the model.

17. The platform of claim 16, further comprising a third computing device connected to the local network, wherein the first computing device is further configured to deploy, from the model use case program operating on the second computing device, the model via the API and to the third computing device.

18. The platform of claim 16, wherein the plurality of data storage devices include a container data storage device configured to operate in a plurality of computing environments, and a distributed data storage device configured to operate on a plurality of computing devices.

19. The platform of claim 16, further comprising a fourth computing device connected to the local network, wherein storing the first data in the plurality of data storage devices comprises sending the first data via a security layer operating on the fourth computing device, the security layer configured to maintain a data security level of the first data.
