



- (51) **International Patent Classification:**
G06N 3/08 (2006.01) G06F 9/50 (2006.01)
G06N 3/04 (2006.01)
- (21) **International Application Number:**
PCT/US2016/061151
- (22) **International Filing Date:**
9 November 2016 (09.11.2016)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
62/253,057 9 November 2015 (09.11.2015) US
- (71) **Applicant:** GOOGLE INC. [US/US]; 1600 Amphitheatre Parkway, Mountain View, CA 94043 (US).
- (72) **Inventors:** YU, Yuan; 1600 Amphitheatre Parkway, Mountain View, CA 94043 (US). VENKATAKRISHNA, Manjunath, Kudlur; 1600 Amphitheatre Parkway, Mountain View, CA 94043 (US).
- (74) **Agents:** GROSVENOR, Stephanie, D. et al.; Fish & Richardson P.C., P.O. Box 1022, Minneapolis, MN 55440-1022 (US).
- (81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

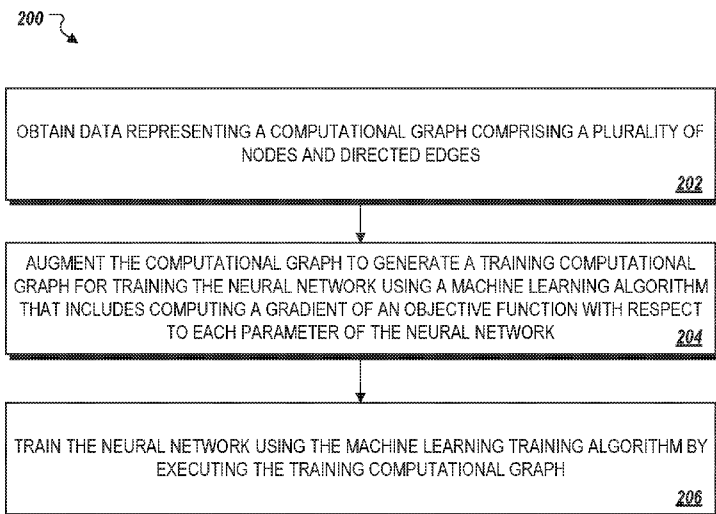
- (84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

[Continued on next page]

(54) **Title:** TRAINING NEURAL NETWORKS REPRESENTED AS COMPUTATIONAL GRAPHS



(57) **Abstract:** Systems and methods for training a neural network represented as a computational graph are disclosed. An example method begins with obtaining data representing a computational graph. The computational graph is then augmented to generate a training computational graph for training the neural network using a machine learning training algorithm that includes computing a gradient of an objective function with respect to each of the parameters of the neural network. Augmenting the computational graph includes inserting a plurality of gradient nodes and training edges into the computational graph to generate a backward path through the computational graph that represents operations for computing the gradients of the objective function with respect to the parameters of the neural network. The neural network is trained using the machine learning training algorithm by executing the training computational graph.

FIG. 2



(88) Date of publication of the international search report:
22 June 2017

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/061151

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06N3/08 G06N3/04 G06F9/50
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
G06N G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>Anonymous: "Automatic differentiation - Wikipedia", 4 November 2015 (2015-11-04), XP055356376, Retrieved from the Internet: URL:https://en.wikipedia.org/w/index.php?title=Automatic_differentiation&oldid=688944133 [retrieved on 2017-03-20] sections "Forward accumulation", "Reverse accumulation"</p> <p style="text-align: center;">----- -/--</p>	1-13,19,20

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search 20 March 2017	Date of mailing of the international search report 24/05/2017
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Archontopoulos, E

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/061151

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Adriana Romero ET AL: "FitNets: hints for thin deep nets", arXiv:1412.6550v4, 27 March 2015 (2015-03-27), XP055349753, Retrieved from the Internet: URL:https://arxiv.org/abs/1412.6550v4 [retrieved on 2017-02-27] abstract sections 2, 5	1-13,19, 20
A	----- WO 98/40824 A1 (AT & T CORP [US]) 17 September 1998 (1998-09-17) abstract page 4, line 9 - last line page 8, line 19 - page 10, line 7 page 18, line 9 - page 19, line 6 page 13, line 13 - page 14, line 2 page 28, line 19 - page 30, line 6	1-13,19, 20
A	----- BOTTOU L ET AL: "GLOBAL TRAINING OF DOCUMENT PROCESSING SYSTEMS USING GRAPH TRANSFORMER NETWORKS", PROCEEDINGS OF THE 1997 IEEE COMPUTER SOCIETY CONFERENCE ON COMPUTER VISION AND PATTERN RECOGNITION. SAN JUAN, PUERTO RICO, JUNE 17 - 19, 1997; [PROCEEDINGS OF THE IEEE COMPUTER SOCIETY CONFERENCE ON COMPUTER VISION AND PATTERN RECOGNITION], LOS ALAM, vol. CONF. 16, 17 June 1997 (1997-06-17), pages 487-494, XP002072348, ISBN: 978-0-7803-4236-1 abstract sections 3, 3.1, 4.1, 5	1-13,19, 20
A	----- Yoav Goldberg: "A Primer on Neural Network Models for Natural Language Processing", 5 October 2015 (2015-10-05), XP055273933, Retrieved from the Internet: URL:http://u.cs.biu.ac.il/~yogo/nnlp.pdf [retrieved on 2016-05-20] sections 6.1, 6.2 -----	1-13,19, 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/061151

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-13, 19, 20

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-13, 19, 20

Distributed execution of operations.

2. claims: 14-18

Aggregating the execution of homogeneous operations.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/061151

Patent document cited in search report	Publication date	Patent family member(s)	Publication date	
WO 9840824	A1	17-09-1998	US 6128606 A	03-10-2000
			WO 9840824 A1	17-09-1998
