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Canada Research Chair
on Statistical Learning Algorithms

Titles and Distinctions

- **Full Professor**, Université de Montréal, since 2002. Previously associate professor (1997-2002) and assistant professor (1993-1997).
- **Canada Research Chair** on *Statistical Learning Algorithms* since 2000 (tier 2 : 2000-2005, tier 1 since 2006).
- **Founder and scientific director of Mila**, the Montreal Institute for Learning Algorithms (formerly the LISA, founded 1993), which brings together the researchers of U. Montréal and McGill in an independent non-profit organization now counting 250 researchers, including 12 faculty. It is the largest academic center for deep learning research in the world, yielding pioneering papers of the area, starting with the introduction of deep learning in 2006, curriculum learning in 2009, showing the power of ReLUs for deeper nets in 2011, and the breakthroughs brought by GANs and neural machine translation in 2014.
- **Scientific Director of IVADO**, the Data Valorization Institute, and leading applicant in the 93.6M\$ CFREF grant (2016-2023) on *Data Serving Canadians : Deep Learning and Optimization for the Knowledge Revolution*, the largest grant ever received at U. Montreal.
- **NSERC Industrial Research Chair** 2005-2015.
- **Recipient** of the 2017 Marie-Victorin Québec Prize (highest distinction in the sciences, for the province of Québec), ACFAS Urgel-Archambault 2009 prize (covering physics, mathematics, computer science, and engineering). Radio-Canada's Scientist of the Year (2017). Lifetime Achievement Award 2018, Canadian AI Association.

- **Member of the Royal Society of Canada** and **Officer of the Order of Canada** since 2017.

- **Senior Fellow**, CIFAR (Canadian Institute For Advanced Research), since 2004. **Co-director** of the CIFAR LMB (Learning in Machines in Brains) program (previously called NCAP) since 2014. This is the program which funded the initial breakthroughs in deep learning and was originally led by Geoff Hinton.

- Member of the board of the **Neural Information Processing Systems (NIPS) Foundation**, since 2010.

- **Action Editor**, *Journal of Machine Learning Research (JMLR)*, *Neural Computation*, *Foundations and Trends in Machine Learning*, and *Computational Intelligence*. Member of the 2012 editor-in-chief nominating committee for JMLR.

- *La Recherche* chose his work on neural networks local minima as one of the 10 highlighted discoveries of 2015.

- Previously **Associate Editor**, *Machine Learning*, *IEEE Trans. on Neural Networks*.

- Member of the board of the Centre de Recherches Mathématiques, UdeM, 1999-2009. Head of the CRM-MILA Lab. Member of the Awards Committee of the Canadian Association for Computer Science (2012-2013). Member of the NIPS'2012 and ICML'2016 committees for best paper awards, and NIPS committees for choosing the next program chairs 2013-2018.

- *Program Co-Chair*, NIPS'2008, *General Chair*, NIPS'2009. Note that *Advances in Neural Information Processing Systems (NIPS)* is a very high level conference, the most important in my field (> 1000 submissions), with reviewing and acceptance criteria comparing favorably to best journals (acceptance rate between 20% and 25%). Having 56 papers published in NIPS over the years puts me among the most prolific contributors to the NIPS community.

- Creation of ICLR (Int. Conf. on Learning Representations) in 2013 and general chair since then. Area chair or member of the program committee (who manage the work of reviewers) for numerous other conferences, including NIPS'95, NIPS'2004, ICML'2003, ICML'2004, ICML'2006, ICML'2008, AISTATS'2001, ICPR'2002, ICNIP'1996, IJCNN'2000, CAP'2004, CAP'2006, CAP'2010, CAP'2011, ICML'2012, ICML'2013, ICML'2014, ICML'2015. Organization of most of the initial deep learning workshops at NIPS and ICML, starting at 2007, and with the first NIPS Symposium on deep learning (2016).

- Member of *grant selection committees* for Quebec's FQRNT (1999-2000), and Canada's NSERC (2000-2003, 2006-2007). Member of CACS/AIC Awards Committee 2012-2015.

- Co-founder of multiple start-ups, including Element AI (2016), which raised a record-breaking 135M\$ for its series A. Leading the effort to connect the Mila with the AI entrepreneurial ecosystem and make Montreal the AI hub of the world, bringing to Montreal AI research labs of Microsoft, Google, Facebook, DeepMind, Samsung and Thalès.

Major Scientific Impact

In August 2018, there were over 129000 citations to scientific publications authored by Yoshua Bengio found by *Google Scholar*, with an H-index of 121, with 37000 citations in 2017 alone. The main research results in career are the following, mostly focused on pioneering the field of deep learning, with major contributions to recurrent neural networks, natural language processing and unsupervised learning.

- 1989-1998 Convolutional and recurrent networks combined with probabilistic alignment (HMMs) to model sequences, as the main contribution of my PhD thesis (1991), NIPS'1988, NIPS'1989, Eurospeech'1991, PAMI'1991, IEEE Trans. Neural Nets 1992. These architectures were first applied to **speech recognition** in my PhD (and rediscovered after 2010) and then with Yann LeCun et al to **handwriting recognition and document analysis** (most cited paper is 'Gradient-based learning applied to document recognition', 1998, with over 10000 citations).

- 1991-1995 **Learning to learn** papers with Samy Bengio, starting with IJCNN 1991, "Learning a synaptic learning rule". The idea of learning to learn (in particular by back-propagating through the whole process) has now become very popular but we lacked the necessary computing power in the early 90's.

- 1993-1995 Uncovering the **fundamental difficulty of learning in recurrent nets** and other machine learning models of temporal dependencies, associated with vanishing and exploding gradients : ICNN'1993, NIPS'1993, NIPS'1994, IEEE Transactions on Neural Nets 1994, NIPS'1995. These papers have had a major impact and motivated later papers on architectures to help learning long-term dependencies and deal with vanishing or exploding gradients. An important but subtle contribution of the IEEE Transactions 1994 paper is to show that the condition required to store bits of information reliably over time also gives rise to vanishing gradients, using dynamical systems theory. The NIPS'1995 paper introduced the use of a hierarchy of time scales to combat the vanishing gradients issue.

- 1999-2014 Understanding how **distributed representations** can bypass the **curse of dimensionality** by providing generalization to an exponentially large set of regions from those comparatively few occupied by training examples. This series of papers also highlights how methods based on local generalization, like nearest-neighbor and Gaussian kernel SVMs lack this kind of generalization ability. The NIPS'1999 introduced for the first time auto-regressive neural networks for density estimation (the ancestor of the NADE and PixelRNN/PixelCNN models). The NIPS'2004, NIPS'2005 and NIPS'2011 papers on this subject show how neural nets can learn a local metric which can bring the

power of generalization of distributed representations to kernel methods and manifold learning methods. Another NIPS'2005 paper shows the fundamental limitations of kernel methods due to a generalization of the curse of dimensionality (the curse of highly variable functions, which have many ups and downs). Finally, the ICLR'2014 paper shows in the case of piecewise-linear networks (like those with ReLUs) that the regions (linear pieces) distinguished by a one-hidden layer network is exponential in the number of neurons (whereas the number of parameters is quadratic in the number of neurons, and a local kernel method would require an exponential number of examples to capture the same kind of function).

- 2000-2008 **Word embeddings from neural networks and neural language models**. The NIPS'2000 paper introduces for the first time the learning of word embeddings as part of a neural network which models language data. The JMLR'2003 journal version expands this (these two papers together get around 3000 citations) and also introduces the idea of **asynchronous SGD** for distributed training of neural nets. Word embeddings have become one of the most common fixtures of deep learning when it comes to language data and this has basically created a new sub-field in the area of computational linguistics. I also introduced the use of importance sampling (AISTATS'2003, IEEE Trans. on Neural Nets, 2008) as well as of a probabilistic hierarchy (AISTATS 2005) to speed-up computations and face larger vocabularies.

- 2006-2014 Showing the **theoretical advantage of depth** for generalization. The NIPS'2006 oral shows experimentally the advantage of depth and is one of the most cited papers in the field (over 2600 citations). The NIPS'2011 paper shows how deeper sum-product networks can represent functions which would otherwise require an exponentially larger model if the network is shallow. Finally, the NIPS'2014 paper on the number of linear regions of deep neural networks generalizes the ICLR'2014 paper mentioned above, showing that the number of linear pieces produced by a piecewise linear network grows exponentially in both width of layers and number of layers, i.e., depth, making the functions represented by such networks generally impossible to capture efficiently with kernel methods (short of using a trained neural net as the kernel).

- 2006-2014 **Unsupervised deep learning** based on auto-encoders (with the special case of GANs as decoder-only models, see below). The NIPS'2006 paper introduced greedy layer-wise pre-training, both the in the supervised case and the unsupervised case with auto-encoders. The ICML'2008 paper introduced **denoising auto-encoders** and the NIPS'2013, ICML'2014 and JMLR'2014 papers cast their theory and generalize them as proper probabilistic models, at the same time introducing alternatives to maximum likelihood as training principles.

- 2014 Dispelling the **local-minima myth** regarding the optimization of neural networks, with the NIPS'2014 paper on saddle points, showing that it is the large number of parameters which makes it very unlikely that bad local minima exist.

- 2014 Introducing **Generative Adversarial Networks (GANs)** at NIPS'2014, which innovates in many ways to train deep generative models, outside of the maximum likelihood framework and even outside of the classical framework of having a single objective function (instead entering into the territory of multiple models trained in a game-theoretical way, each with their objective). One of the hottest research areas in deep learning, as of this writing, with almost 2000 citations mostly from papers which introduce variants of

GANs, which have been producing impressively realistic synthetic images one would not imagine computers being able to generate just a few years ago.

• 2014-2016 Introducing **content-based soft attention** and the breakthrough it brought to **neural machine translation**, mostly with Kyunghyun Cho and Dima Bahdanau. We first introduced the encoder-decoder (now called sequence-to-sequence) architecture (EMNLP'2014) and then achieved a big jump in BLEU scores with content-based soft attention (ICLR'2015). These ingredients are now the basis of most commercial machine translation systems. Another whole sub-field has been created using these techniques.

Academic Studies and Diplomas

1992–1993	Post-doctoral Fellow, Learning and vision algorithms , Larry Jackel and Yann LeCun's group, AT&T Bell Laboratories, New-Jersey.
1991–1992	Post-doctoral Fellow, NSERC scholarship, Statistical learning / sequential data , Michael I. Jordan's group, Brain and Cognitive Sciences Dept., MIT, Massachusetts.
1988–1991	Ph.D. in computer science, NSERC scholarship, Neural Networks and Markovian Models , Computer Science Dept., McGill University.
1986–1988	M.Sc. in computer science , CGPA 4.0/4.0, <i>Speech recognition with statistical methods</i> , Computer Science Dept., McGill University.
1982–1986	B.Eng. in computer engineering , <i>Honours class, CGPA 3.82/4.0</i> Electrical Engineering Dept., McGill University.

Graduate Students & Post-docs

Current :

Postdoc : Min Lin, Devansh Arpit, Jason Jo, Joseph Paul Cohen, Mirco Ravanelli.

Phd : Vincent Dumoulin, Guillaume Alain, Bart Merriënboer, Jessica Thompson, Taesup Kim, Julian Vlad Serban, Dmitrii Serdiuk, Saizheng Zhang, Benjamin Scellier, Dzmitry Bahdanau, Sarath Chandar Anbil Parthipan, Chinnadhurai Sankar, Sandeep Subramanian, Zhouhan Lin, Yaroslav Ganin, Tong Che, Tristan Sylvain, Sherjil Ozair, Akram Erraqabi, Mathieu Courbariaux, Valentin Thomas, Won Lee, William Fedus, Giancarlo Kerg, Salem Lahlou.

MSc : Stephanie Larocque, Philippe Lacaille, Anirudh Goyal, Francis Dutil, Olexa Bilaniuk, Samuel Lavoie-Marchildon.

Former (graduated) :

Postdoc : Devon Hjelm (2018), Adriana Romero Soriano (2017), Philemon Brakel (2017), Nicolas Ballas (2017), Sungjin Ahn (2016), Asja Fischer (2016), Jorg Bornschein (2015), Kyung-Hyun Cho (2015), Jyri Kivinen (2014), Heng Luo (2013), Aaron Courville (2011), Antoine Bordes (2011), Joseph Turian (2010), Michael Mendel (2010), Jerome Louradour (2008), Marina Sokolova (2007), Pierre-Jean L'Heureux (2006), Christopher Kermorvant (2005), Xiangdong Wang (2003), Gilles Caporossi (2002), Ichiro Takeuchi (2001), Takafumi Kanamori (2001), Claude Nadeau (2000), Stephen Langdell (2000), Holger Schwenk (1997), Samy Bengio (1996).

PhD : Laurent Dinh (2018), Junyoung Chung (2018), Caglar Gulcehre (2018), David Warde-Farley (2017), Li Yao (2017), Mehdi Mirza (2017), Yann Dauphin (2015), Xavier Glorot (2015), Razvan Pascanu (2014), Ian Goodfellow (2014), Guillaume Desjardins (2014), Nicolas Boulanger-Lewandoski (2013), Philippe Hamel (2012), Olivier Delalleau (2012), James Bergstra (2011), Dumitru Erhan (2011), François Rivest (2010), Nicolas Chapados (2009), Hugo Larochelle (2009), Nicolas Le Roux (2008), Julie Carreau (2008), Narjes Boufaden (2005), Pascal Vincent (2003), Charles Dugas (2003), Joumana Ghosn (2002), Steven Pigeon (2001), François Gingras (1999).

MSc : Dong-Hyun Lee (2018), Kelvin Xu (2017), Soroush Mehri (2016), Samira Shabani (2016), Jose Rodriguez Sotelo (2016), Kyle Kastner (2016), David Krueger (2016), Matthieu Courbariaux (2015), Pierre Luc Carrier (2014), Eric Thibodeau-Laufer (2014), Nicholas Leonard (2014), Valentin Bisson (2012), François Savard (2011), Olivier Breuleux (2010), Guillaume Desjardins (2009), Pierre-Antoine Manzagol (2007), Dumitru Erhan (2006), Marie Ouimet (2004), Christian Dorion (2004), Maryse Boisvert (2004), Frédéric Morin (2004), Francis Piérault (2003), Jean-François Paiement (2003), Jean-Sébastien Senecal (2003), Lynian Meng (2002), Nicolas Chapados (2000), Vincent-Philippe Lauzon (1999), Simon Latendresse (1999), Julien Desaulnier (1998).

Main Grants

Current

- Microsoft, unrestricted gift, 1.2M\$/yr × 5 years, 2016-2021
- Facebook, unrestricted equipment gift, 1.5M\$, 2017
- CFREF grant (Data for Canadians), 93.6M\$, 2016-2023
- CFI Cyberinfrastructure grant, 5M\$, 2016-2019
- NSERC CRD grants, 200k\$/yr, 2016-2018
- Panasonic, unrestricted gift, 200k \$US in 2017, 300k \$US in 2018
- NSERC + IBM collaborative R&D grant, 800k\$ over 3 years, 2015-2018
- Google focused research award, 250k\$US per year, 2016-2019
- Samsung GRP DL grant, 550k US\$/yr × 3 yrs, 2017-2020

- Samsung GRP NPP grant, 100k\$/yr \times 3 yrs, 2015-2018
- Nuance Foundation grants (2), 2 \times 200k\$/yr \times 4 yrs, 2014-2018
- NSERC discovery grant, 76k\$/yr \times 5 yrs, 2014-2019
- Canada Research Chair, 200k\$/yr, since 2006

Previous (past 4 years) in addition to above

- Samsung GRP DL grant, 500k\$/yr \times 2 yrs, 2014-2016
- Panasonic research sponsorship, 250k\$, 2016
- NSERC equipment grant, 135k\$, 2016
- NSERC strategic grants (2), 240k\$ + 220k\$/yr \times 3 yrs, 2013-2016
- NSERC-Ubisoft CRD grants, 50k+80k\$/yr, 2011-2016
- Google Focused Research Award, 200k\$/yr, 2014 and 2015
- NSERC-Ubisoft industrial chair, 350k\$/yr \times 5 yrs, 2011-2016
- Facebook Academics gift, 50k\$, 2014
- NSERC Idea to Innovation grant, 124k\$, 2012
- NSERC strategic grant, \sim 70% of \sim 120k\$/yr \times 3 yrs, 2009-2012
- NSERC Engage grants, 25k\$ \times 4, 2010, 2011, 2013.
- NSERC-CGI industrial chair, 150k\$/yr \times 5 yrs, 2005-2010
- MITACS NCE grant, \sim 30% of \sim 130k\$/yr \times 11 yrs, 1999-2011
- NSERC strategic grant, \sim 50% of 99k\$/yr \times 2 yrs, 2008-2010
- NSERC Engage grant, 25k\$, 2011.
- NSERC collaborative R&D grant, \sim 50% of \sim 73k\$/yr \times 2 yrs, 2007-2009
- Google Research Award, 50k\$, 2008
- NSERC discovery grant, 70k\$/yr \times 5 yrs, 2009-2014
- NSERC discovery grant, 56k\$/yr \times 5 yrs, 2004-2009
- Bell University Labs, \sim 75k\$/yr \times 10 yrs, 1999-2008
- IRIS NCE grant, \sim 30% of \sim 150k\$/yr \times 11 yrs, 1993-2005
- Canada Research Chair, 100k\$/yr, since 2000-2005
- CIHR NET grant, \sim 5% of 250k\$/yr \times 6 yrs, 2002-2008
- NSERC collaborative R&D grant, 45k\$/yr \times 2 yrs, 2003-2005
- NSERC collaborative R&D grant, 56k\$/yr \times 2 yrs, 2004-2006

Partial List of Co-Authors

Yann LeCun, Geoff Hinton, Aaron Courville, Pascal Vincent, Vladimir Vapnik, Leon Bottou, Hugo Larochelle, Ronan Collobert, Ian Goodfellow, Antoine Bordes, Nicolas Le Roux, Samy Bengio, James Bergstra, Yves Grandvalet, Xavier Glorot, Jason Weston, Douglas Eck, Marco Gori, Juergen Schmidhuber, Dumitru Erhan, Olivier Chapelle, Lise Getoor, Thomas Breuel, Joseph Turian, Patrice Marcotte, Balazs Kegl, Tomas Mikolov, David Warde-Farley, Guido Montufar, Gal Chechik, Andrew Fitzgibbon, Patrick Haffner, Razvan Pascanu, Guillaume Desjardins, Patrice Simard, Salah Rifai, Pascal Lamblin, Kyunghyun Cho, Heng Luo, Yann Dauphin, Jean-Luc Gauvain, Renato De Mori, Paolo Frasconi, Caglar Gulcehre, Dzmitry Bahdanau, Jason Yosinski, Frederic Bastien, Jan

Chorowski, Jorg Bornschein, Gregoire Mesnil, Nicolas Boulanger-Lewandowski, Junyoung Chung, Li Yao, Kelvin Xu, Alessandro Sordoni, Sherjil Ozair, Richard Zemel, Sepp Hochreiter, Saizheng Zhang, Dmitriy Serkyuk, Vincent Dumoulin, Chris Pal, Joelle Pineau, Jamie Kiros, Asja Fischer, Jeff Clune, Li Deng, Bing Xu, Laurent Dinh, Takeuchi Ichiro, Patrice Marcotte, Felix Hill, Heng Luo, Nicholas Leonard, Stephan Gouws

2 Research Contributions

2.1 Refereed Journal Publications

- [1] I. Hubara, M. Courbariaux, D. Soudry, R. El-Yaniv, and Y. Bengio, “Quantized neural networks : Training neural networks with low precision weights and activations,” *Journal of Machine Learning Research*, vol. 18, no. 187, pp. 1–30, 2018.
- [2] C. Gulcehre, S. Chandar, K. Cho, and Y. Bengio, “Dynamic neural turing machine with continuous and discrete addressing schemes,” *Neural Computation*, vol. 30, no. 4, pp. 857–884, 2018.
- [3] G. Derevyanko, S. Grudinin, Y. Bengio, and G. Lamoureaux, “Deep convolutional networks for quality assessment of protein folds,” *Bioinformatics*, 2018.
- [4] M. Ravanelli, P. Brakel, M. Omologo, and Y. Bengio, “Light gated recurrent units for speech recognition,” *IEEE Transactions on Emerging Topics in Computational Intelligence*, vol. 2, no. 2, pp. 92–102, 2018.
- [5] H. Choi, K. Cho, and Y. Bengio, “Fine-grained attention mechanism for neural machine translation,” *Neurocomputing*, vol. 284, pp. 171–176, 2018.
- [6] X.-Y. Zhang, F. Yin, Y.-M. Zhang, C.-L. Liu, and Y. Bengio, “Drawing and recognizing chinese characters with recurrent neural network,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 40, no. 4, pp. 849–862, 2018.
- [7] M. Drozdal, G. Chartrand, E. Vorontsov, M. Shakeri, L. D. Jorio, A. Tang, A. Romero, Y. Bengio, C. Pal, and S. Kadoury, “Learning normalized inputs for iterative estimation in medical image segmentation,” *Medical image analysis*, vol. 44, pp. 1–13, 2018.
- [8] P. D. Luna, J. Wei, Y. Bengio, A. Aspuru-Guzik, and E. Sargent, “Use machine learning to find energy materials,” *Nature*, vol. 552, pp. 23–27, 2017.
- [9] F. Hill, K. Cho, S. Jean, and Y. Bengio, “The representational geometry of word meanings acquired by neural machine translation models,” *Machine Translation*, pp. 1–16, 2017.
- [10] M. Havaei, A. Davy, D. Warde-Farley, A. Biard, A. Courville, Y. Bengio, C. Pal, P.-M. Jodoin, and H. Larochelle, “Brain tumor segmentation with deep neural networks,” *Medical Image Analysis*, vol. 35, pp. 18 – 31, 2017.
- [11] Y. Bengio, T. Mesnard, A. Fischer, S. Zhang, and Y. Wu, “STDP-compatible approximation of back-propagation in an energy-based model,” *Neural Computation*, vol. 29, no. 3, pp. 555–577, 2017.
- [12] Ç. Gülçehre, O. Firat, K. Xu, K. Cho, and Y. Bengio, “On integrating a language model into neural machine translation,” *Computer Speech & Language*, vol. 45, p. 137–148, 2017.
- [13] X.-Y. Zhang, Y. Bengio, and C.-L. Liu, “Online and offline handwritten chinese character recognition : A comprehensive study and new benchmark,” *Pattern Recognition*, vol. 61, pp. 348–360, 2017.
- [14] X.-Y. Zhang, G.-S. Xie, C.-L. Liu, and Y. Bengio, “End-to-end online writer identification with recurrent neural network,” *IEEE Transactions on Human-Machine Systems*, vol. 47, no. 2, pp. 285–292, 2017.

- [15] H. Choi, K. Cho, and Y. Bengio, "Context-dependent word representation for neural machine translation," *arXiv e-prints*, vol. abs/1607.00578, July 2016.
- [16] O. Firat, K. Cho, B. Sankaran, F. T. Y. Vural, and Y. Bengio, "Multi-way, multilingual neural machine translation," *Computer Speech & Language*, 2016.
- [17] Y. Bengio, "Springtime for AI : The rise of deep learning," *Scientific American*, June 2016.
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- [22] Ç. Gülçehre and Y. Bengio, "Knowledge matters : Importance of prior information for optimization," *Journal of Machine Learning Research*, vol. 17, no. 8, pp. 1–32, 2016.
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