Game	Human	IW(1) RAM	IW(1) budget .5s	IW(1) budget 32s	Rollout IW(1) budget .5s	Rollout IW(1) budget 32s	RA Rollout IW(1) budget .5s	RA Rollout IW(1) budget 32s	RAS Rollout IW(1) budget .5s	RAS Rollout IW(1) budget 32s
alien	6,875.0	**25,634.0**	1,316.0	14,010.0	4,238.0	6,896.0	7,170.0	13,454.0	8,550.0	19,354.0
amidar	1,676.0	1,377.0	48.0	1,043.2	659.8	1,698.6	1,049.2	**1,794.0**	1,161.0	1,609.0
assault	**1,496.0**	953.0	268.8	336.0	285.6	319.2	336.0	327.6	264.6	281.4
asterix	8,503.0	153,400.0	1,350.0	**262,500.0**	45,780.0	66,100.0	46,100.0	67,100.0	48,700.0	87,600.0
asteroids	13,157.0	**51,338.0**	840.0	7,630.0	4,344.0	7,258.0	4,698.0	6,836.0	4,486.0	7,344.0
atlantis	29,028.0	**159,420.0**	33,160.0	82,060.0	64,200.0	151,120.0	122,220.0	134,660.0	113,460.0	134,660.0
bank heist	734.4	717.0	24.0	739.0	272.0	865.0	242.0	1,323.4	268.0	**2,179.0**
battle zone	37,800.0	11,600.0	6,800.0	14,800.0	39,600.0	414,000.0	74,600.0	455,800.0	56,200.0	**509,400.0**
beam rider	5,775.0	**9,108.0**	715.2	1,530.4	2,188.0	2,464.8	2,552.8	5,367.2	3,729.2	4,921.2
berzerk	n/a	**2,096.0**	280.0	1,318.0	644.0	862.0	1,208.0	1,454.0	966.0	1,640.0
bowling	**154.8**	69.0	30.6	49.2	47.6	45.8	44.2	49.0	51.6	48.0
boxing	4.3	**100.0**	99.4	79.0	75.4	79.4	99.2	**100.0**	78.6	80.2
breakout	31.8	**384.0**	1.6	56.0	82.4	36.0	86.2	336.4	79.8	370.0
centipede	11,963.0	99,207.0	88,890.0	**143,275.4**	36,980.2	65,162.6	56,328.0	92,353.0	46,661.4	84,226.0
chopper command	9,882.0	10,980.0	1,760.0	1,800.0	2,920.0	5,800.0	9,820.0	11,240.0	8,900.0	**33,220.0**
crazy climber	35,411.0	36,160.0	16,780.0	**44,340.0**	39,220.0	43,960.0	40,440.0	38,460.0	38,120.0	42,720.0
defender	n/a	n/a	362,010.0	**430,010.0**	373,010.0	256,010.0	371,010.0	374,010.0	298,010.0	387,010.0
demon attack	3,401.0	20,116.0	106.0	**23,619.0**	2,780.0	9,996.0	6,958.0	10,753.0	5,201.0	9,898.0
double dunk	-15.5	-14.0	-22.0	-22.4	3.6	**20.0**	3.2	19.6	-4.0	16.0
elevator action	n/a	**13,480.0**	1,080.0	0.0	0.0	0.0	0.0	0.0	0.0	1,300.0
enduro	309.6	**500.0**	2.6	229.2	169.4	359.4	145.8	381.0	137.4	330.8
fishing derby	5.5	**30.0**	-83.8	-39.0	-68.0	-16.2	-77.0	-50.2	-61.8	-53.0
freeway	29.6	**31.0**	0.6	25.0	2.8	12.6	2.0	11.2	3.6	10.0
frostbite	4,335.0	902.0	106.0	182.0	220.0	5,484.0	146.0	**6,398.0**	1,494.0	5,970.0
gopher	2,321.0	18,256.0	1,036.0	**18,472.0**	7,216.0	13,176.0	8,388.0	13,144.0	7,256.0	11,840.0
gravitar	2,672.0	3,920.0	380.0	1,630.0	1,630.0	3,700.0	1,660.0	5,130.0	2,410.0	**5,540.0**
hero	25,673.0	12,985.0	2,034.0	7,432.0	13,709.0	28,260.0	11,377.0	24,072.0	11,480.0	**29,708.0**
ice hockey	0.9	**55.0**	-13.6	-7.0	-6.0	6.6	-12.4	-2.6	5.2	18.2
james bond	406.7	**23,070.0**	40.0	180.0	450.0	22,250.0	10,760.0	12,656.0	5,340.0	12,345.0
kaboom	n/a	n/a	127.0	178.2	87.4	159.6	23.2	151.6	39.8	255.6
kangaroo	3,035.0	**8,760.0**	160.0	3,820.0	1,080.0	5,780.0	1,880.0	4,600.0	1,800.0	5,280.0
krull	2,395.0	**6,030.0**	3,206.8	5,611.8	1,892.8	1,151.2	2,091.8	2,219.8	1,645.2	2,837.0
kung fu master	22,736.0	**63,780.0**	440.0	8,980.0	2,080.0	14,920.0	2,620.0	26,540.0	2,980.0	24,300.0
montezuma's revenge	**4,367.0**	0.0	0.0	0.0	0.0	0.0	100.0	1,620.0	100.0	1,080.0
ms pacman	15,693.0	21,695.0	2,578.0	20,622.8	9,178.4	19,667.0	15,115.0	**23,033.0**	13,746.8	21,833.0
name this game	4,076.0	9,354.0	7,070.0	**13,478.0**	6,226.0	5,980.0	6,558.0	6,870.0	6,128.0	6,820.0
phoenix	n/a	n/a	1,266.0	5,550.0	5,750.0	**7,636.0**	6,790.0	7,460.0	5,386.0	7,570.0
pitfall	n/a	n/a	**-8.6**	-92.2	-81.4	-130.8	-302.8	-723.4	-814.6	-692.4
pong	9.3	**21.0**	-20.8	0.8	-7.4	17.6	-4.2	15.2	-1.4	18.2
private eye	**69,571.0**	-99.0	2,690.8	-526.4	-322.0	3,157.2	-480.0	-300.0	2,160.0	-340.0
qbert	13,455.0	3,705.0	515.0	16,505.0	3,375.0	8,390.0	15,970.0	26,875.0	14,160.0	**40,350.0**
riverraid	13,513.0	5,694.0	664.0	7,042.0	6,088.0	8,156.0	6,288.0	14,700.0	7,138.0	**15,302.0**
road runner	7,845.0	**94,940.0**	200.0	0.0	2,360.0	37,080.0	31,140.0	44,020.0	25,780.0	62,960.0
robotank	11.9	**68.0**	3.2	32.8	31.0	52.6	31.2	47.4	30.0	51.8
seaquest	**20,182.0**	14,272.0	168.0	356.0	980.0	10,932.0	2,312.0	13,472.0	1,236.0	9,846.0
skiing	n/a	n/a	-16,511.0	-15,962.0	-15,738.4	-16,477.0	-16,006.4	**-15,244.2**	-15,806.6	-15,473.6
solaris	n/a	n/a	1,356.0	**2,300.0**	700.0	1,040.0	1,704.0	692.0	1,620.0	1,728.0
space invaders	1,652.0	2,877.0	280.0	1,963.0	2,628.0	1,980.0	1,149.0	2,533.0	1,812.0	**4,362.0**
star gunner	10,250.0	1,540.0	840.0	1,340.0	13,360.0	15,640.0	14,900.0	16,460.0	15,960.0	**17,160.0**
tennis	-8.9	**24.0**	-23.4	-22.2	-18.6	-2.2	-5.4	14.8	3.2	-3.4
time pilot	5,925.0	**35,000.0**	2,360.0	5,740.0	7,640.0	8,140.0	3,540.0	5,480.0	8,540.0	5,480.0
tutankham	167.7	172.0	71.2	172.4	128.4	184.0	135.6	**191.6**	147.4	191.2
up n down	9,082.0	**110,036.0**	928.0	62,378.0	36,236.0	44,306.0	34,668.0	39,964.0	36,936.0	41,056.0
venture	1,188.0	**1,200.0**	0.0	240.0	0.0	80.0	60.0	500.0	80.0	120.0
video pinball	17,298.0	388,712.0	28,706.4	**441,094.2**	203,765.4	382,294.8	216,468.6	378,815.4	188,604.4	375,073.0
wizard of wor	4,757.0	**121,060.0**	5,660.0	115,980.0	37,220.0	73,820.0	43,860.0	84,660.0	40,780.0	75,380.0
yars revenge	n/a	n/a	6,352.6	10,808.2	5,225.4	9,866.4	7,848.8	**23,261.8**	3,647.8	10,523.6
zaxxon	9,173.0	29,240.0	0.0	15,080.0	9,280.0	22,880.0	15,500.0	34,180.0	18,700.0	**38,700.0**
# ≥ Human	n/a	n/a	7 (14.2%)	22 (44.8%)	19 (38.7%)	34 (69.3%)	22 (44.8%)	35 (71.4%)	25 (51.0%)	**37 (75.5%)**
# ≥ 75% Human	n/a	n/a	7 (14.2%)	24 (48.9%)	22 (44.8%)	34 (69.3%)	26 (53.0%)	39 (79.5%)	29 (59.1%)	**40 (81.6%)**
# best in game	5 (8.6%)	**24 (41.3%)**	1 (1.7%)	9 (15.5%)	0 (0.0%)	2 (3.4%)	0 (0.0%)	7 (12.0%)	0 (0.0%)	11 (18.9%)

Table 2: Scores over 58 games for Human, IW(1) over RAM, and IW(1) and three versions of Rollout IW(1) with time budgets of 0.5 and 32 seconds. Entries marked as n/a are not available, those highlighted in bold are best scores across rows, and those highlighted in red are scores as good as human playing (except for IW(1) over RAM). The 9 games for which there are no reports for the human player are not considered when comparing the different algorithms with the human player.
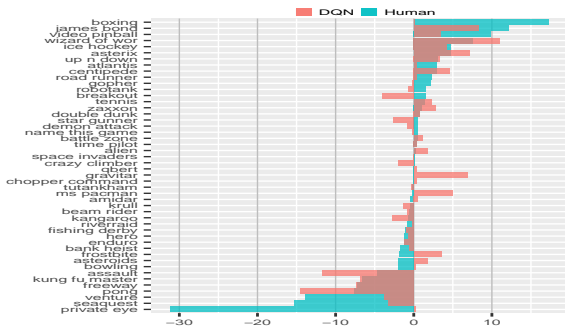
Figure 3: Comparison of RAS Rollout IW(1) with time budget of 0.5 seconds with the human player and DQN using relative scores over 48 games. Blue bars depict RAS Rollout IW(1) scores (r) vs. human scores (h), while red bars, RAS Rollout IW(1) scores vs. DQN scores (d). The bar has positive length $(r - h)/h$ when $r > h$, and negative length $(h - r)/r$ when $r < h$. Bars have zero length when $r = h$. Same for d in place of h.

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