

# Algorithms for Non-Linear Programming

This repository contains implementations of various algorithms for solving non-linear programming problems.

## Getting Started

Install Python 3.10

```
sudo apt-get install python3.10-full
```

Install Venv Package

```
sudo apt-get install python3-venv
```

Create a virtual environment

```
python3.10 -m venv env
```

Activate the virtual environment

```
source env/bin/activate
```

Install the required packages

```
pip install -r requirements.txt
```

## How to Use

Run the specific problem script, for example:

```
python problem1.py
```

or run the main script to execute all problems:

```
python run_all_problems.py
```

To convert the markdown file to a PDF, use the following command:

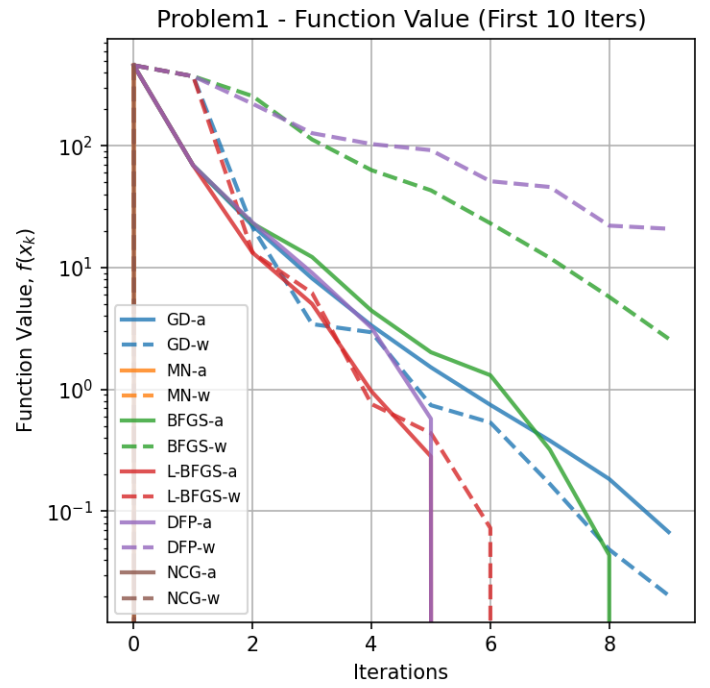
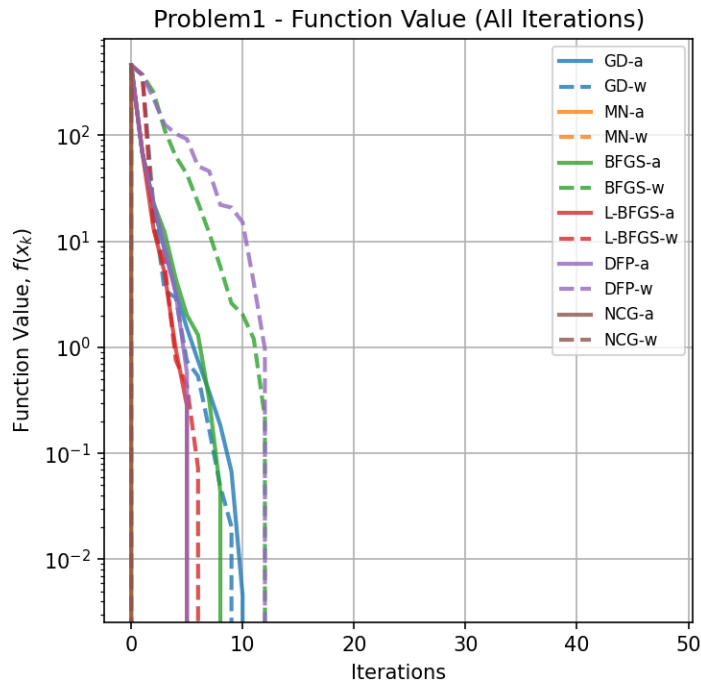
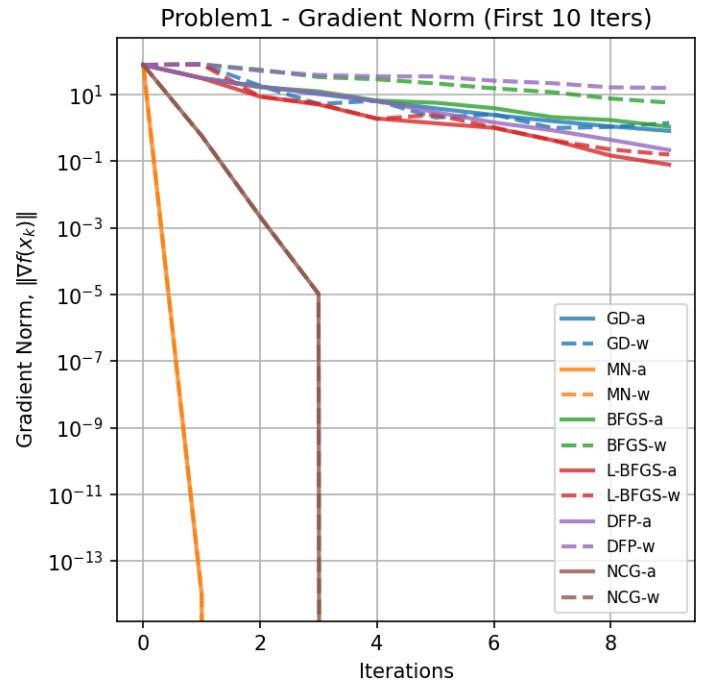
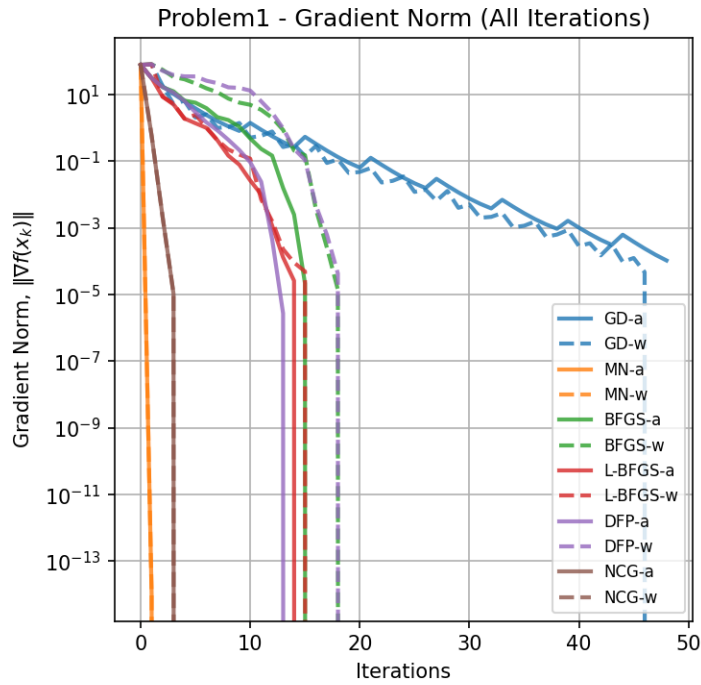
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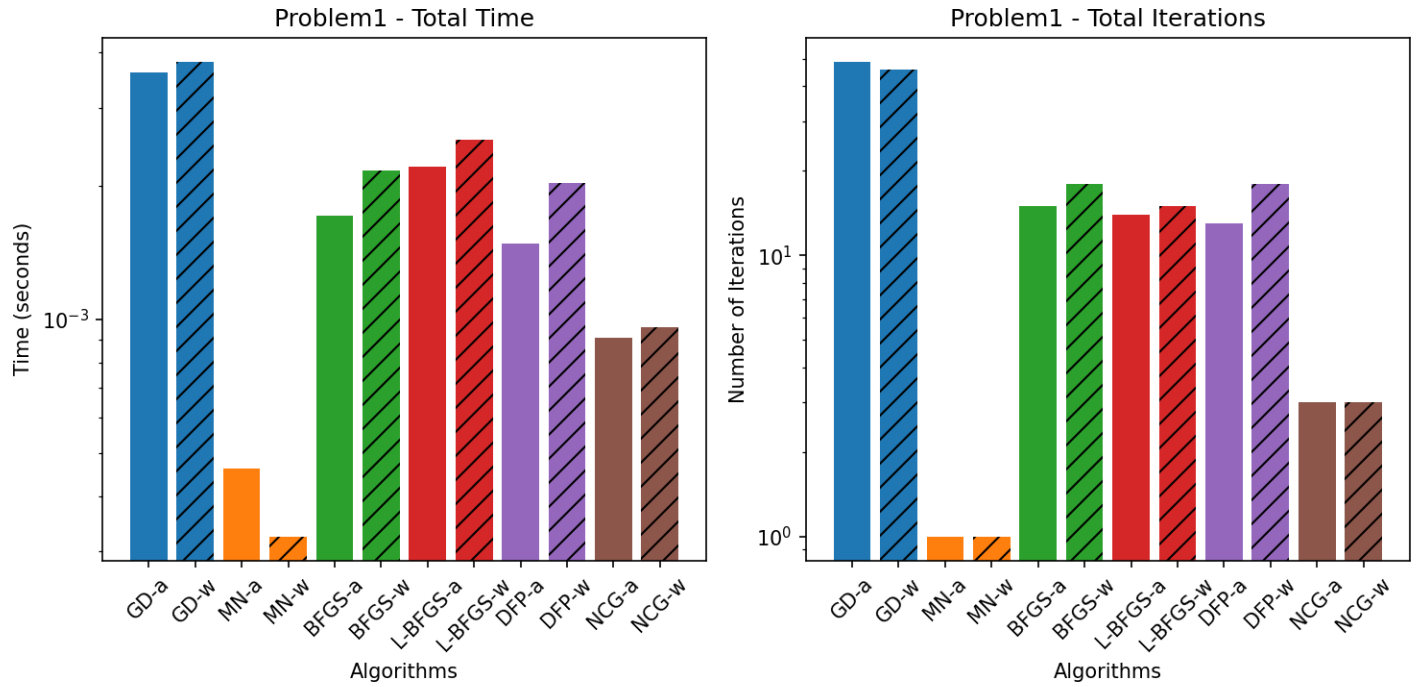
## Results

Plots for each problem will be saved in the **figures** directory. Data for each problem will be saved in the **data** directory.

### Problem 1

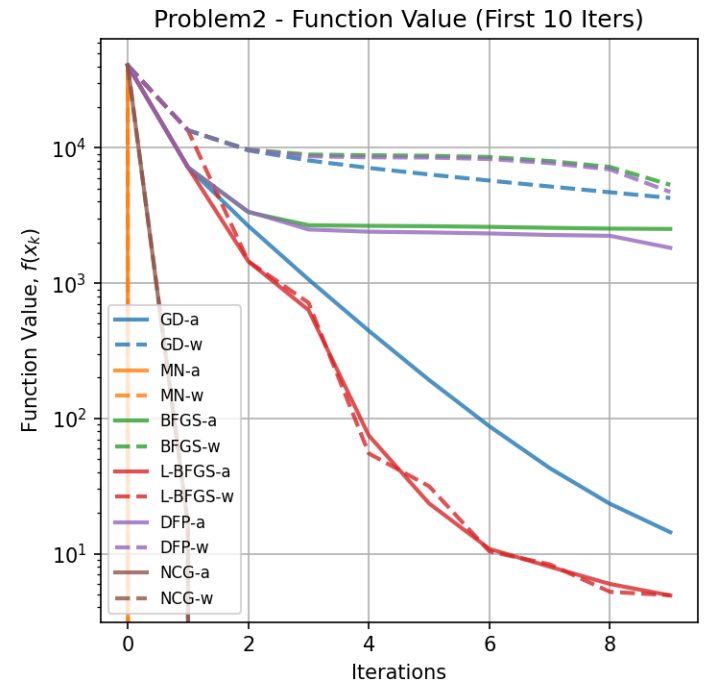
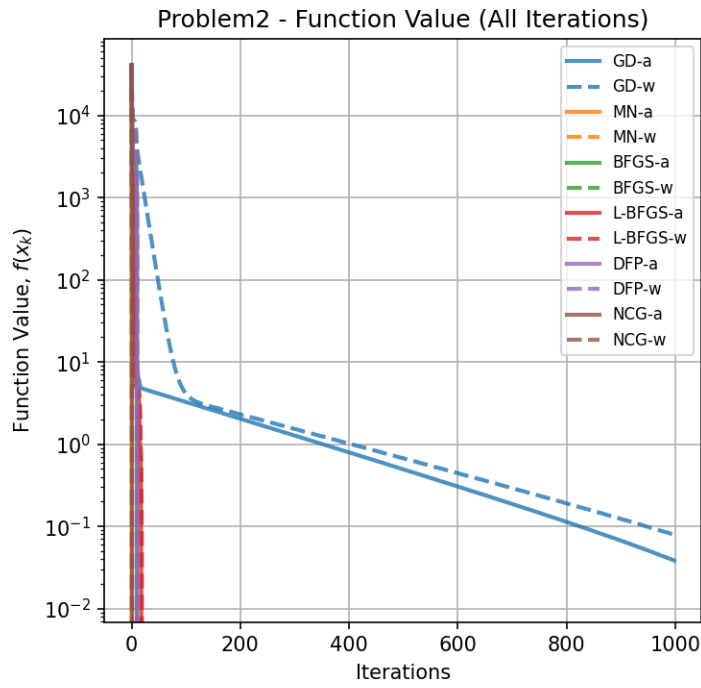
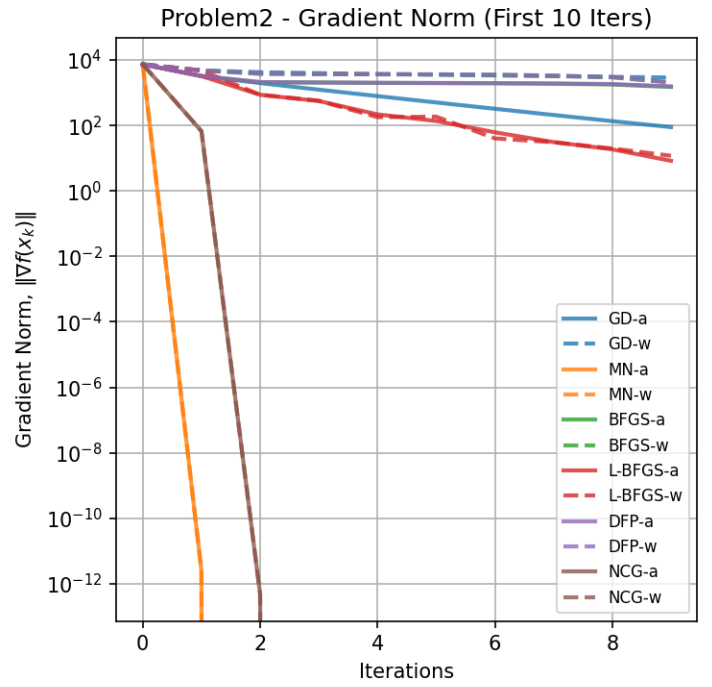
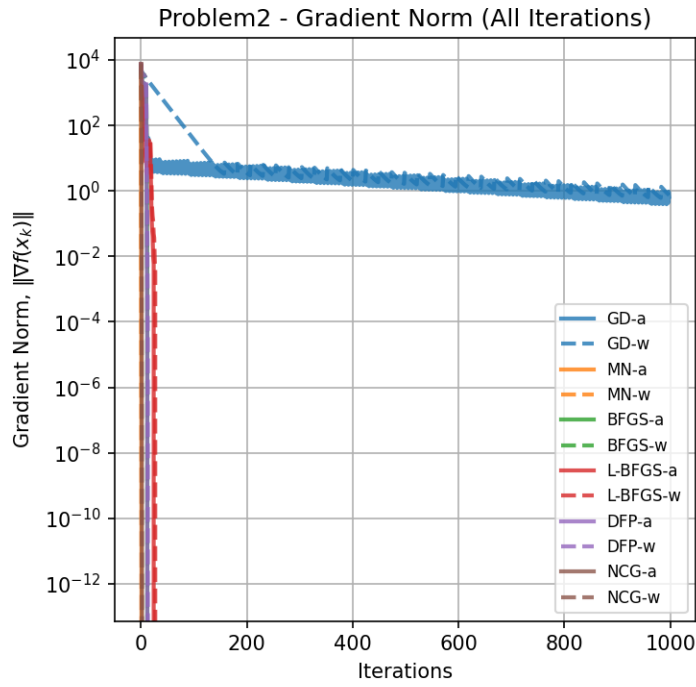
	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	49	0.00360322	Converged. Gradient norm is below tolerance.	190	99	0
GD-w	46	0.00380874	Converged. Gradient norm is below tolerance.	202	47	0
MN-a	1	0.000460863	Converged. Gradient norm is below tolerance.	3	4	2
MN-w	1	0.000324011	Converged. Gradient norm is below tolerance.	3	3	2
BFGS-a	15	0.00171161	Converged. Gradient norm is below tolerance.	44	47	0
BFGS-w	18	0.00216508	Converged. Gradient norm is below tolerance.	49	38	0
L-BFGS-a	14	0.00221252	Converged. Gradient norm is below tolerance.	32	43	0
L-BFGS-w	15	0.00253296	Converged. Gradient norm is below tolerance.	33	31	0
DFP-a	13	0.00148416	Converged. Gradient norm is below tolerance.	40	41	0
DFP-w	18	0.0020268	Converged. Gradient norm is below tolerance.	41	38	0
NCG-a	3	0.000909805	Converged. Gradient norm is below tolerance.	7	8	4
NCG-w	3	0.000962019	Converged. Gradient norm is below tolerance.	7	5	4

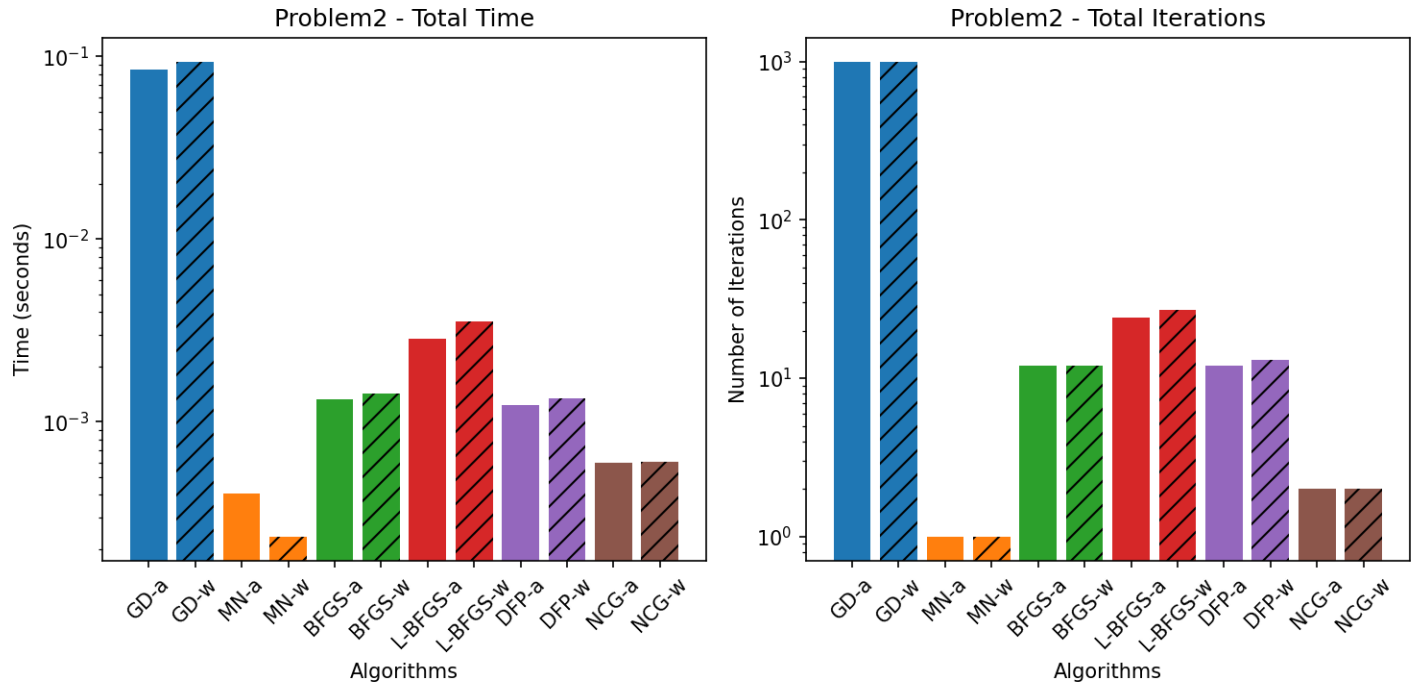




## Problem 2

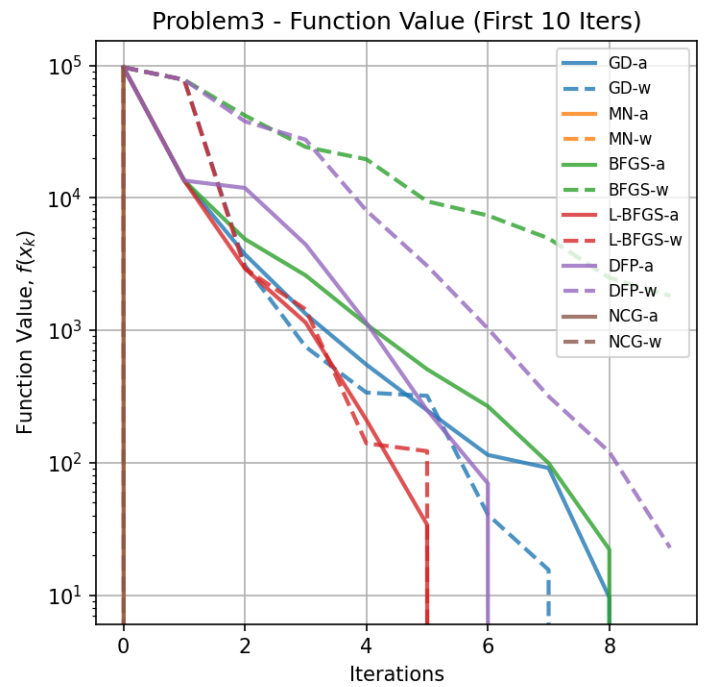
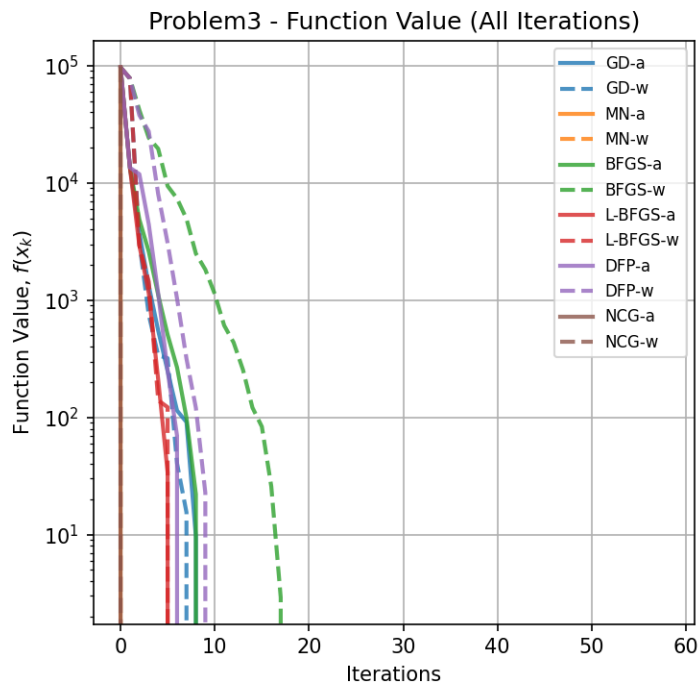
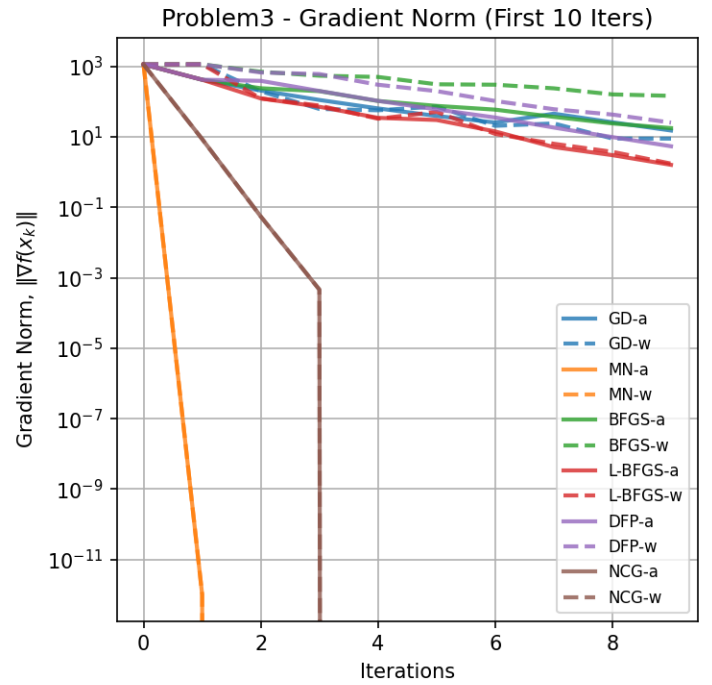
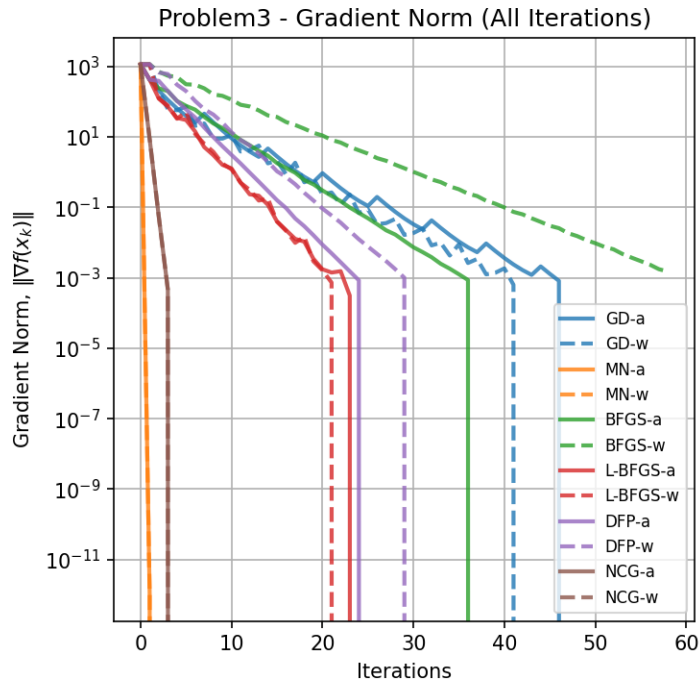
	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	999	0.0852475	Failed. Maximum iterations reached.	8722	2000	0
GD-w	999	0.0937407	Failed. Maximum iterations reached.	10965	1000	0
MN-a	1	0.000406504	Converged. Gradient norm is below tolerance.	3	4	2
MN-w	1	0.000235081	Converged. Gradient norm is below tolerance.	3	3	2
BFGS-a	12	0.00132084	Converged. Gradient norm is below tolerance.	81	38	0
BFGS-w	12	0.00143337	Converged. Gradient norm is below tolerance.	100	26	0
L-BFGS-a	24	0.00286078	Converged. Gradient norm is below tolerance.	56	73	0
L-BFGS-w	27	0.00352979	Converged. Gradient norm is below tolerance.	67	55	0
DFP-a	12	0.00122952	Converged. Gradient norm is below tolerance.	71	38	0
DFP-w	13	0.0013504	Converged. Gradient norm is below tolerance.	81	28	0
NCG-a	2	0.000596523	Converged. Gradient norm is below tolerance.	5	6	3
NCG-w	2	0.000603676	Converged. Gradient norm is below tolerance.	5	4	3

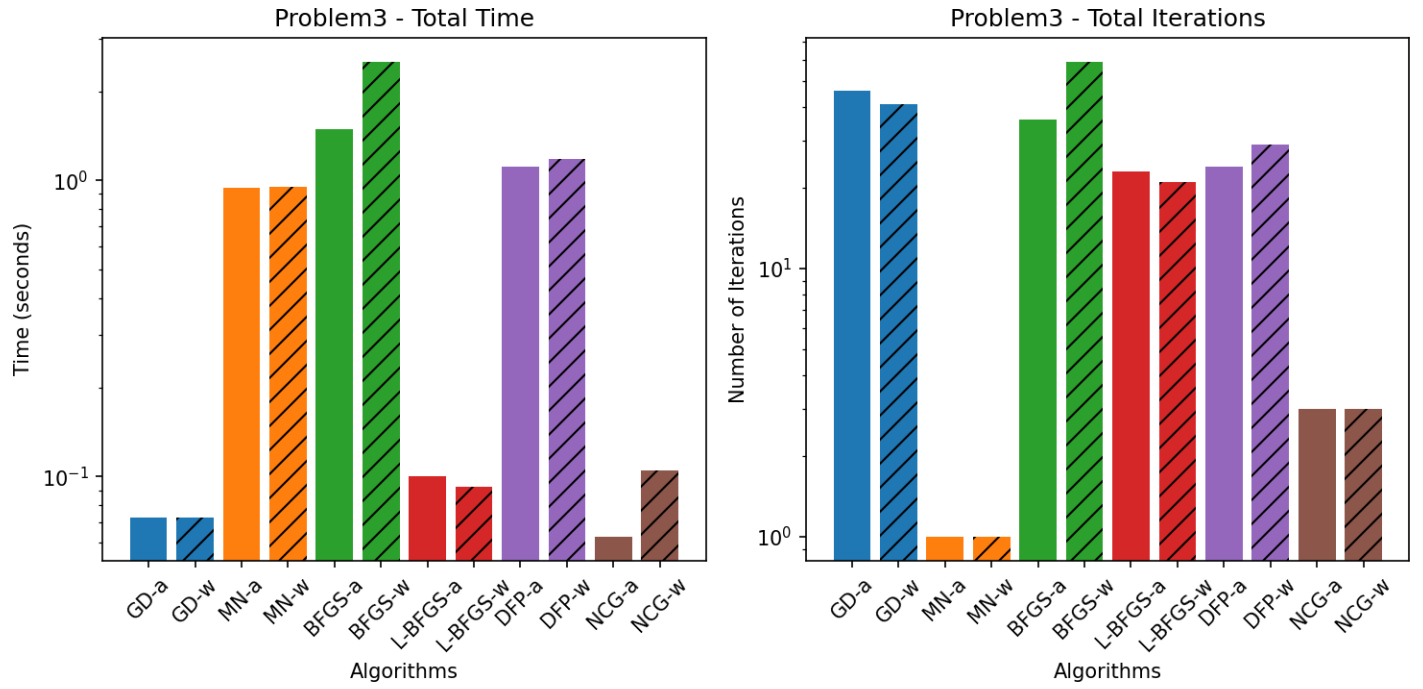




### Problem 3

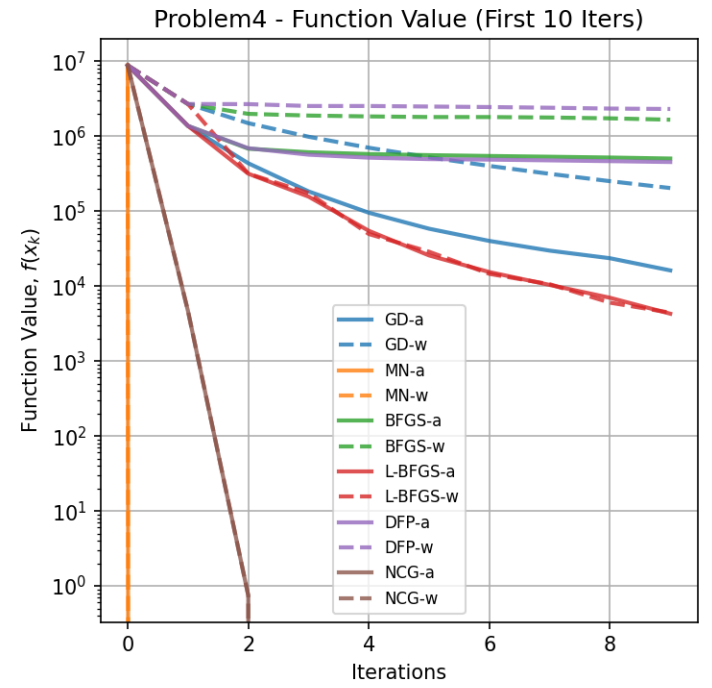
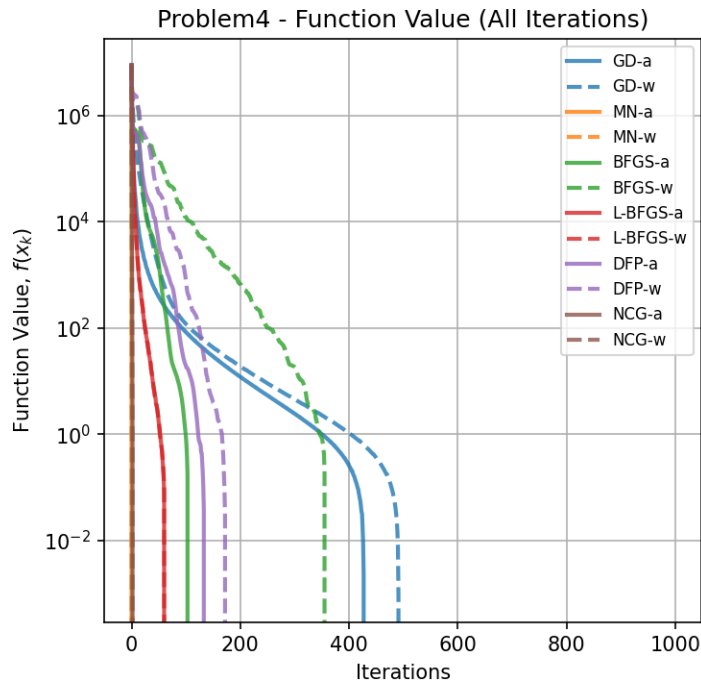
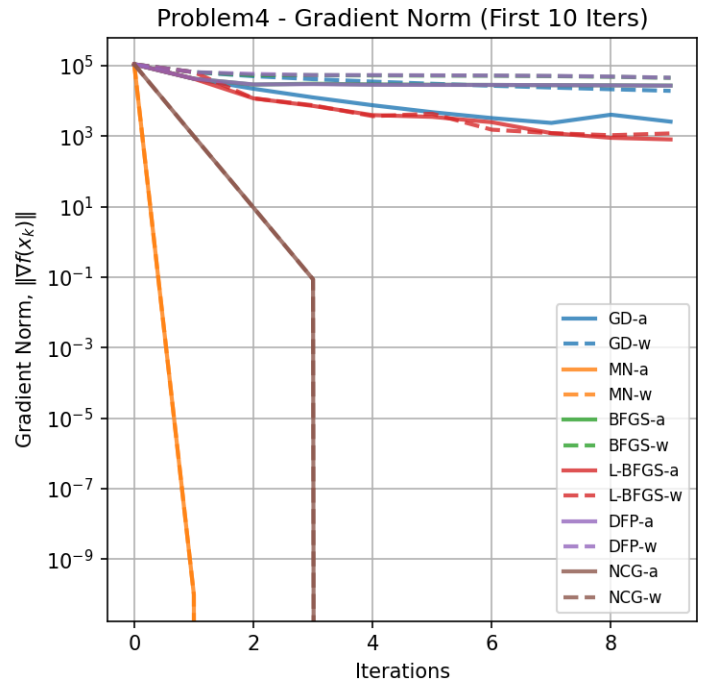
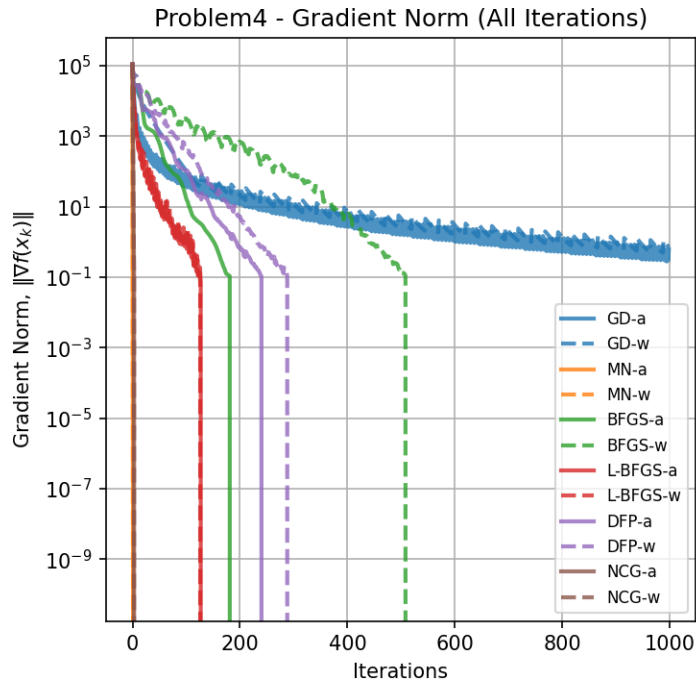
	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	46	0.072953	Converged. Gradient norm is below tolerance.	178	93	0
GD-w	41	0.0725338	Converged. Gradient norm is below tolerance.	180	42	0
MN-a	1	0.945208	Converged. Gradient norm is below tolerance.	3	4	2
MN-w	1	0.949564	Converged. Gradient norm is below tolerance.	3	3	2
BFGS-a	36	1.48786	Converged. Gradient norm is below tolerance.	111	110	0
BFGS-w	59	2.51835	Converged. Gradient norm is below tolerance.	179	120	0
L-BFGS-a	23	0.100574	Converged. Gradient norm is below tolerance.	51	70	0
L-BFGS-w	21	0.0926821	Converged. Gradient norm is below tolerance.	46	43	0
DFP-a	24	1.1155	Converged. Gradient norm is below tolerance.	74	74	0
DFP-w	29	1.18345	Converged. Gradient norm is below tolerance.	88	60	0
NCG-a	3	0.0627294	Converged. Gradient norm is below tolerance.	7	8	4
NCG-w	3	0.105006	Converged. Gradient norm is below tolerance.	7	5	4



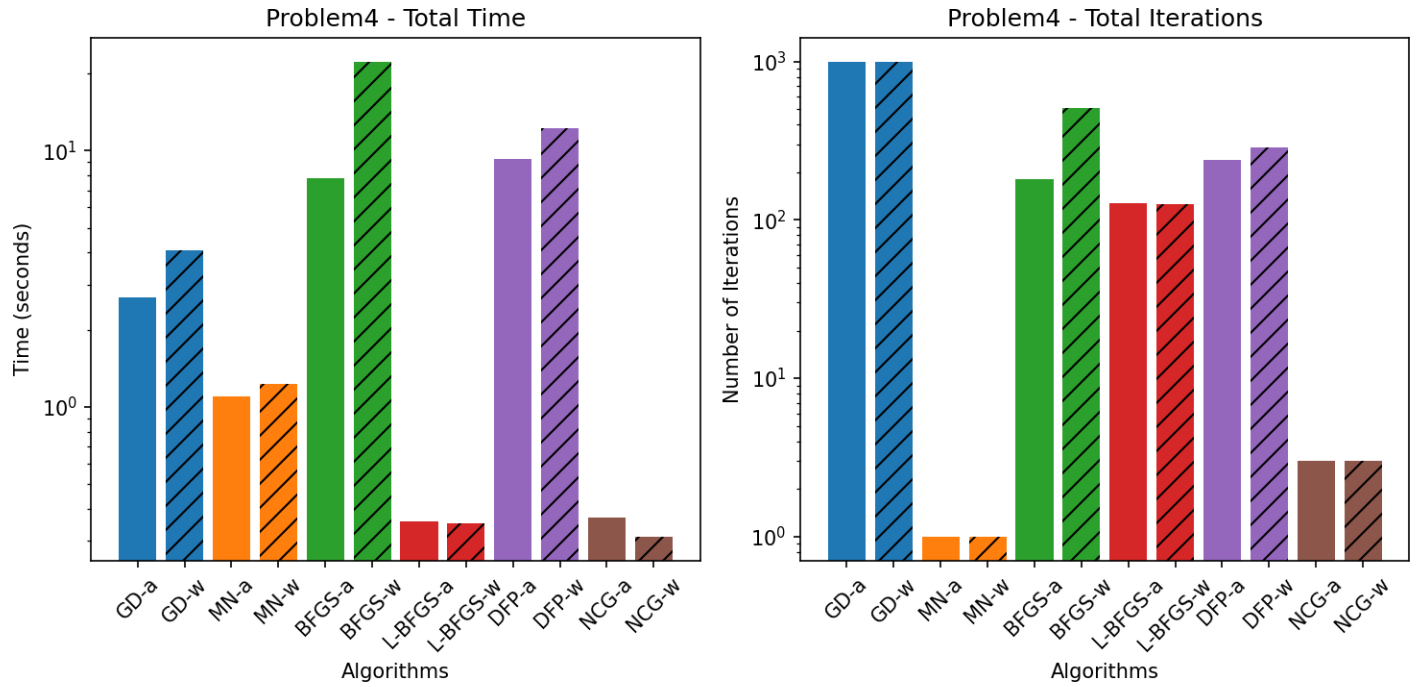


#### Problem 4

	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	999	2.66288	Failed. Maximum iterations reached.	8722	2000	0
GD-w	999	4.07727	Failed. Maximum iterations reached.	10965	1000	0
MN-a	1	1.10098	Converged. Gradient norm is below tolerance.	3	4	2
MN-w	1	1.22952	Converged. Gradient norm is below tolerance.	3	3	2
BFGS-a	181	7.80866	Converged. Gradient norm is below tolerance.	1451	545	0
BFGS-w	508	22.2446	Converged. Gradient norm is below tolerance.	4779	1018	0
L-BFGS-a	127	0.356493	Converged. Gradient norm is below tolerance.	267	382	0
L-BFGS-w	126	0.349955	Converged. Gradient norm is below tolerance.	267	253	0
DFP-a	240	9.3101	Converged. Gradient norm is below tolerance.	1268	722	0
DFP-w	288	12.2225	Converged. Gradient norm is below tolerance.	1750	578	0
NCG-a	3	0.371059	Converged. Gradient norm is below tolerance.	7	8	4
NCG-w	3	0.31185	Converged. Gradient norm is below tolerance.	7	5	4

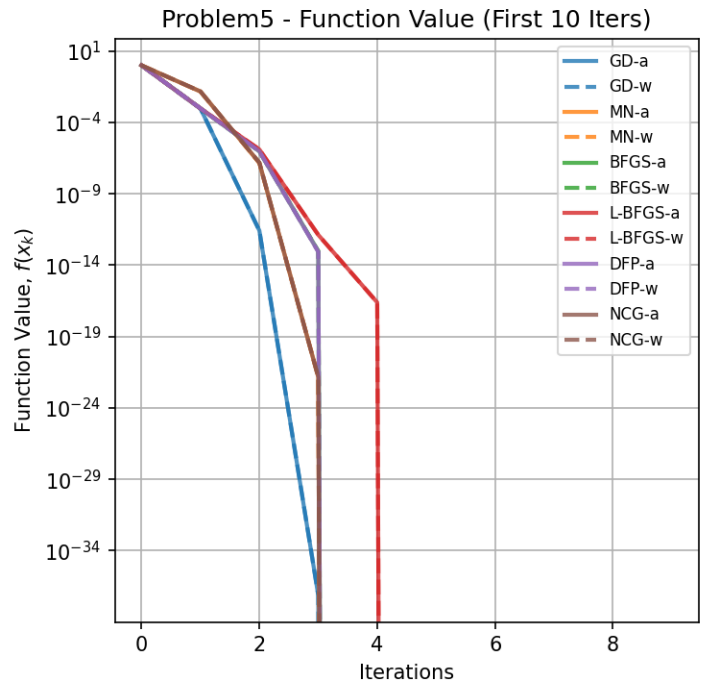
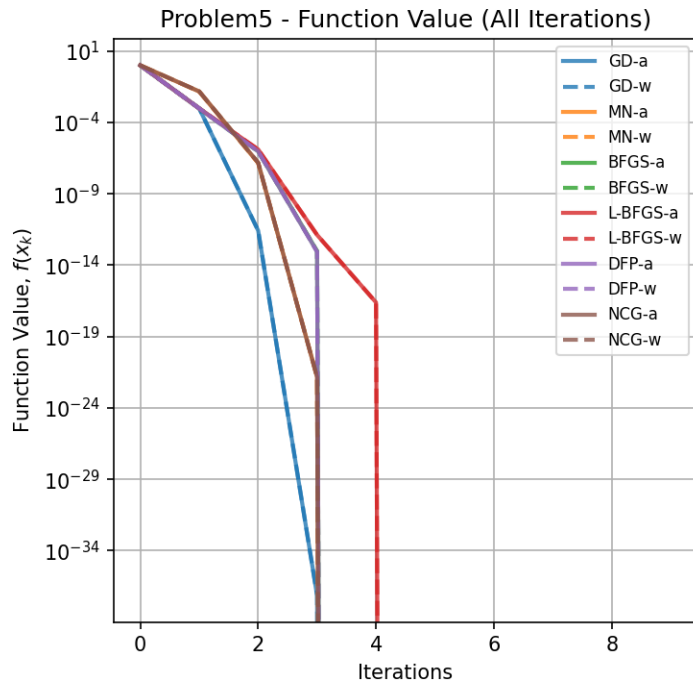
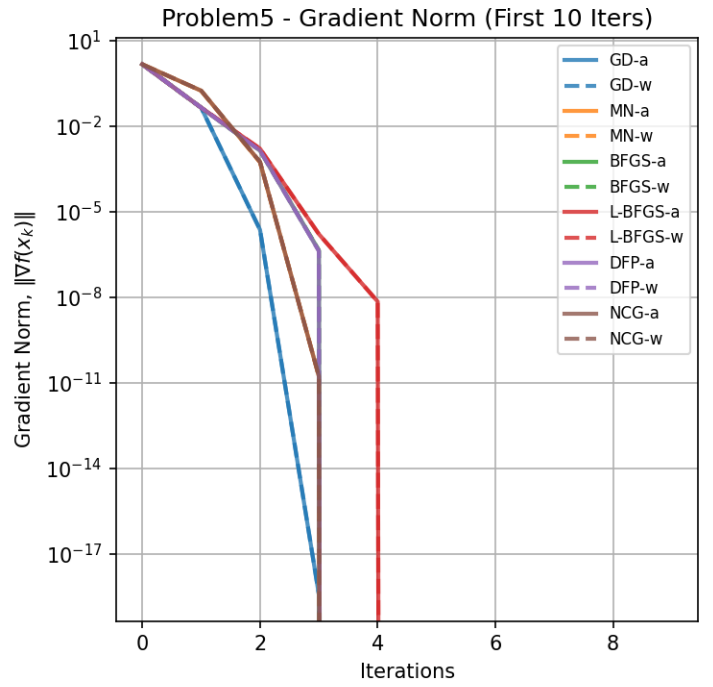
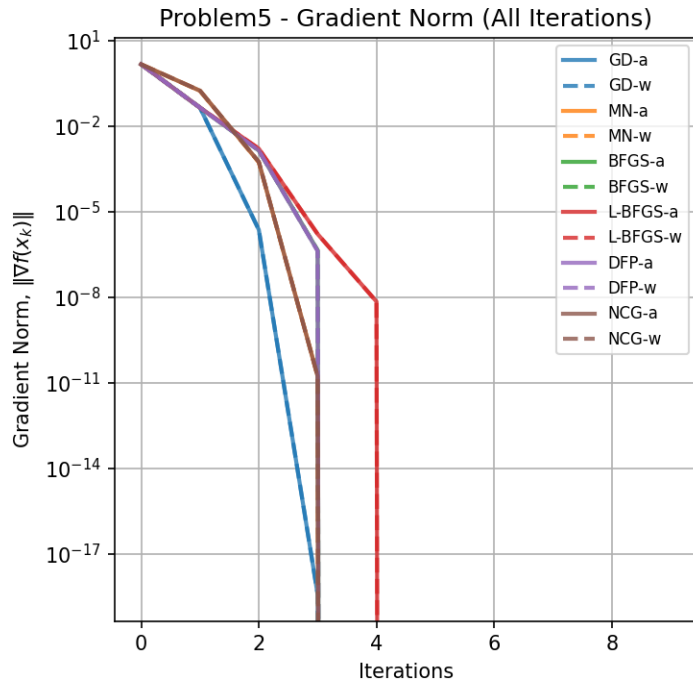


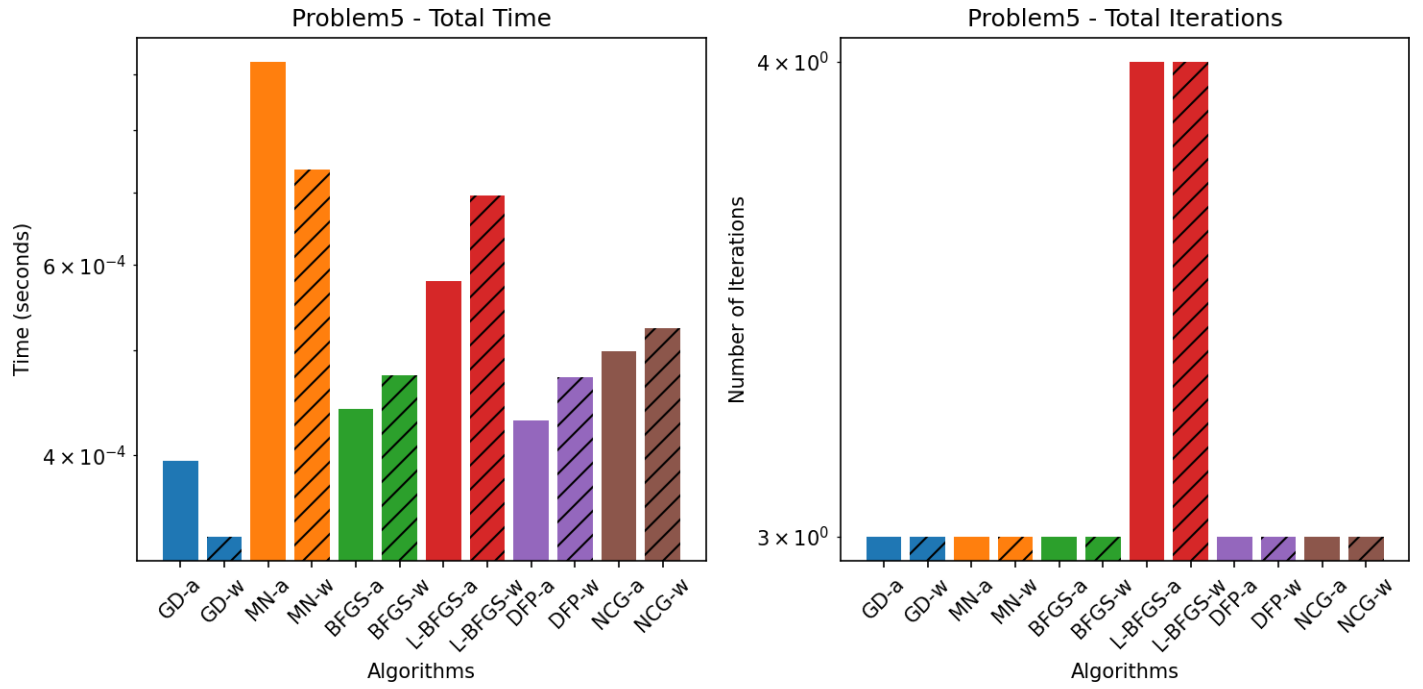




### Problem 5

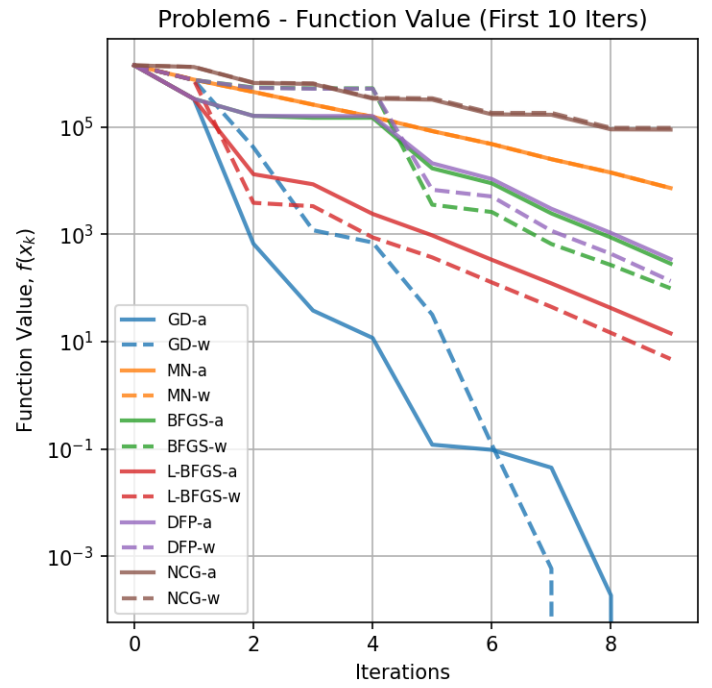
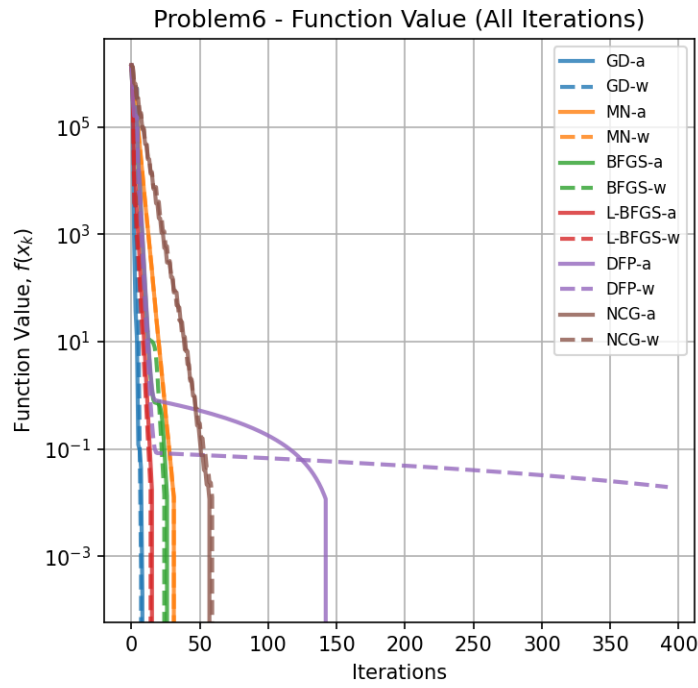
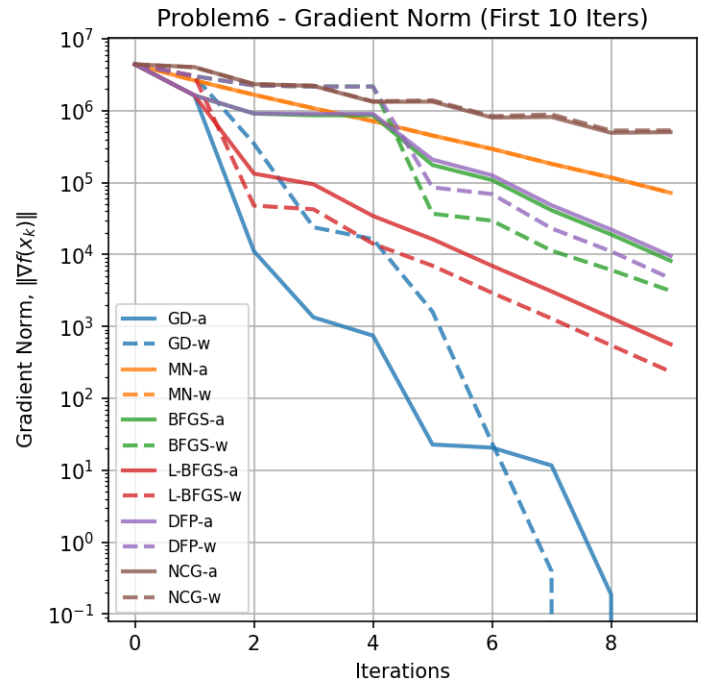
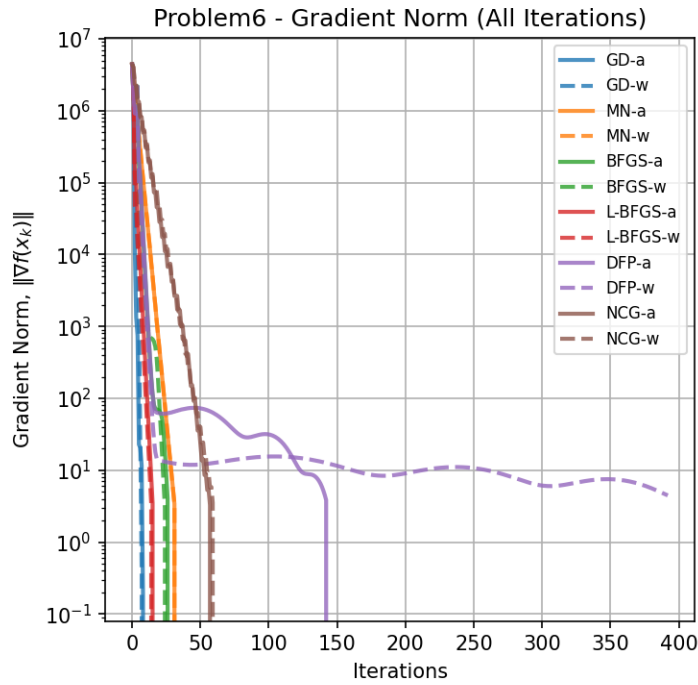
	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	3	0.000395536	Converged. Gradient norm is below tolerance.	7	7	0
GD-w	3	0.000336409	Converged. Gradient norm is below tolerance.	7	4	0
MN-a	3	0.000925064	Converged. Gradient norm is below tolerance.	7	8	4
MN-w	3	0.00073576	Converged. Gradient norm is below tolerance.	7	5	4
BFGS-a	3	0.000441313	Converged. Gradient norm is below tolerance.	7	11	0
BFGS-w	3	0.000474691	Converged. Gradient norm is below tolerance.	7	8	0
L-BFGS-a	4	0.000579357	Converged. Gradient norm is below tolerance.	9	13	0
L-BFGS-w	4	0.000695467	Converged. Gradient norm is below tolerance.	9	9	0
DFP-a	3	0.000430822	Converged. Gradient norm is below tolerance.	7	11	0
DFP-w	3	0.000472307	Converged. Gradient norm is below tolerance.	7	8	0
NCG-a	3	0.000498772	Converged. Gradient norm is below tolerance.	7	8	4
NCG-w	3	0.000524521	Converged. Gradient norm is below tolerance.	7	5	4

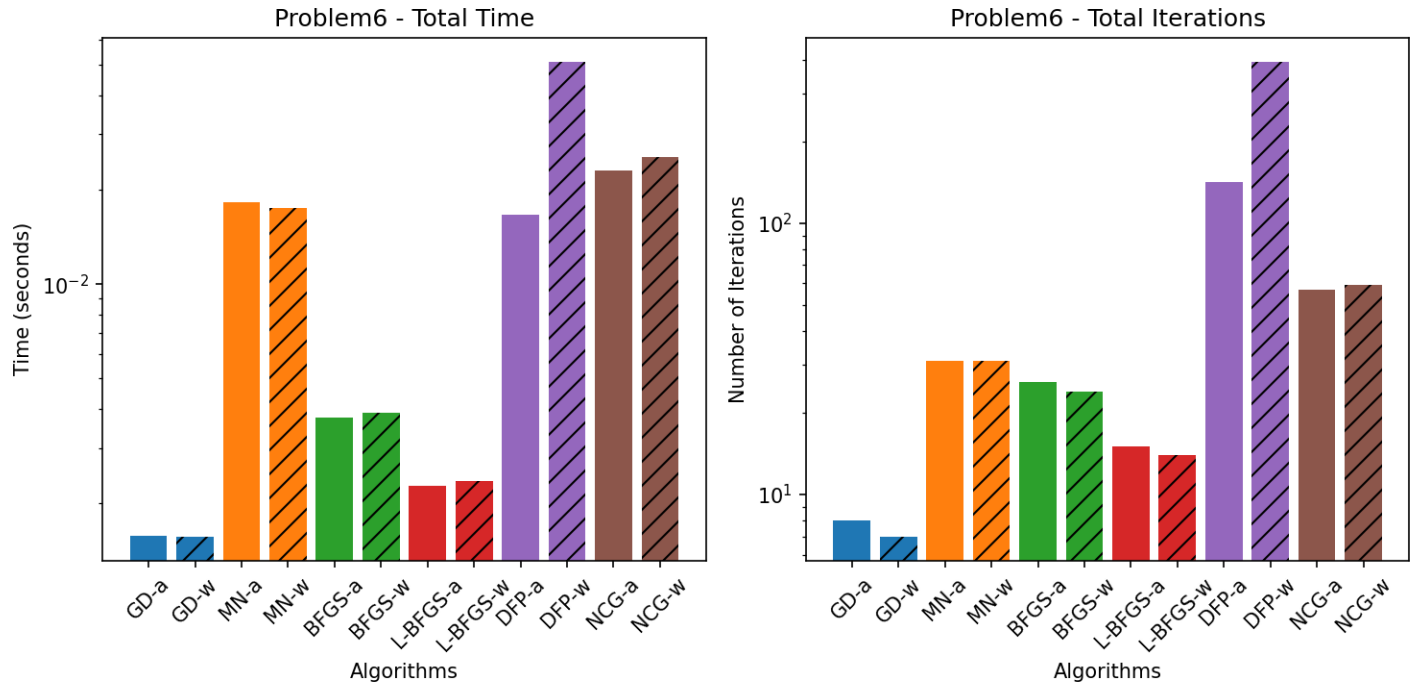




### Problem 6

	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	8	0.00157738	Converged. Gradient norm is below tolerance.	102	17	0
GD-w	7	0.00156951	Converged. Gradient norm is below tolerance.	132	8	0
MN-a	31	0.0182481	Converged. Gradient norm is below tolerance.	63	64	32
MN-w	31	0.0174356	Converged. Gradient norm is below tolerance.	63	33	32
BFGS-a	26	0.00375772	Converged. Gradient norm is below tolerance.	113	80	0
BFGS-w	24	0.00390363	Converged. Gradient norm is below tolerance.	129	50	0
L-BFGS-a	15	0.00227237	Converged. Gradient norm is below tolerance.	47	46	0
L-BFGS-w	14	0.00236773	Converged. Gradient norm is below tolerance.	50	29	0
DFP-a	142	0.0166104	Converged. Gradient norm is below tolerance.	344	428	0
DFP-w	393	0.0511451	Converged. Gradient norm is below tolerance.	867	788	0
NCG-a	57	0.0229957	Converged. Gradient norm is below tolerance.	611	116	58
NCG-w	59	0.0253308	Converged. Gradient norm is below tolerance.	898	61	60

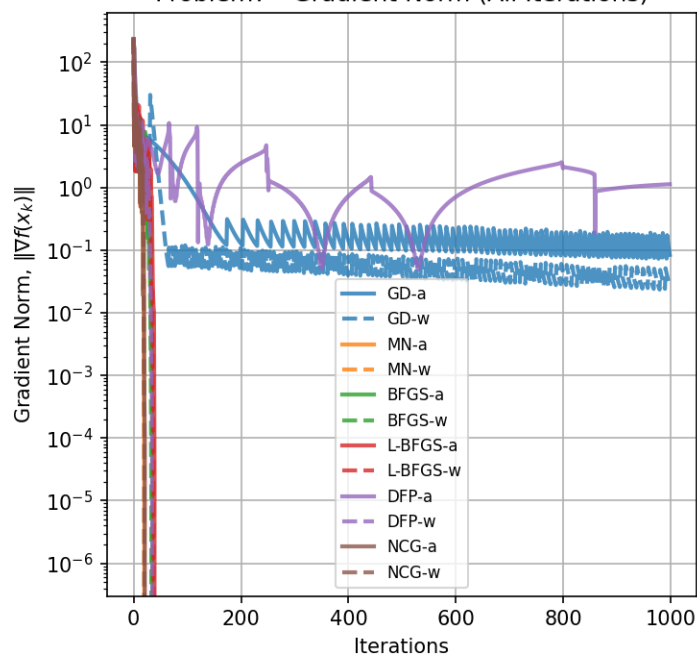




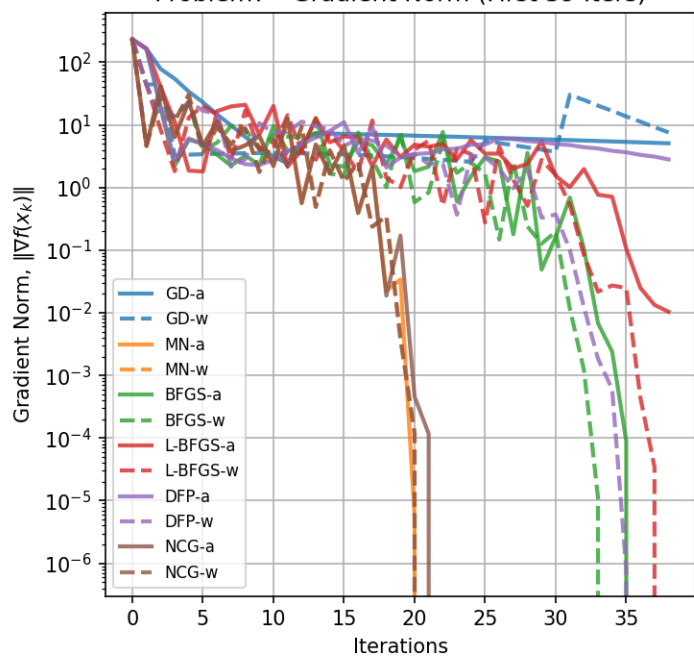
### Problem 7

	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	999	0.0857866	Failed. Maximum iterations reached.	8923	2000	0
GD-w	999	0.0853806	Failed. Maximum iterations reached.	10881	1001	0
MN-a	20	0.00281167	Converged. Gradient norm is below tolerance.	47	42	21
MN-w	20	0.00283647	Converged. Gradient norm is below tolerance.	48	22	21
BFGS-a	35	0.00335741	Converged. Gradient norm is below tolerance.	90	107	0
BFGS-w	33	0.00367308	Converged. Gradient norm is below tolerance.	86	68	0
L-BFGS-a	39	0.00447989	Converged. Gradient norm is below tolerance.	108	118	0
L-BFGS-w	37	0.00418043	Converged. Gradient norm is below tolerance.	95	83	0
DFP-a	999	0.0932341	Failed. Maximum iterations reached.	2031	3001	0
DFP-w	35	0.00395656	Converged. Gradient norm is below tolerance.	88	76	0
NCG-a	21	0.00224209	Converged. Gradient norm is below tolerance.	49	44	22
NCG-w	20	0.00249839	Converged. Gradient norm is below tolerance.	48	22	21

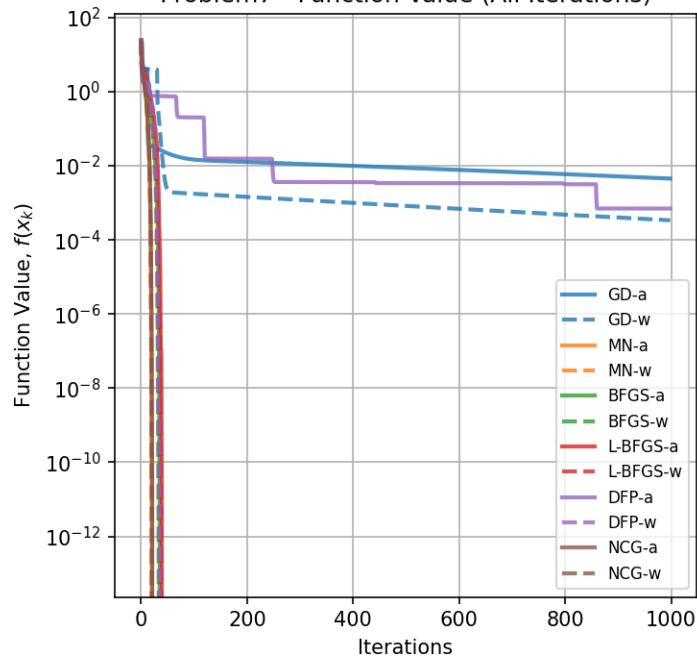
Problem7 - Gradient Norm (All Iterations)



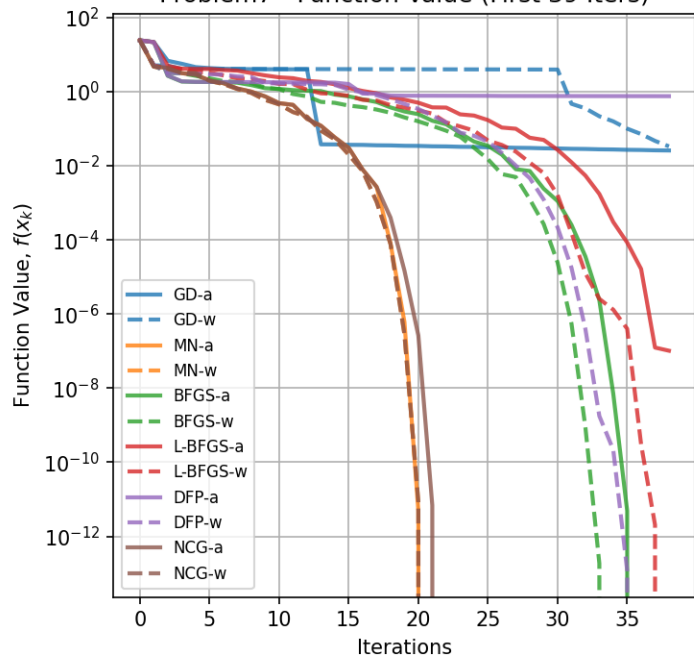
Problem7 - Gradient Norm (First 39 Iters)

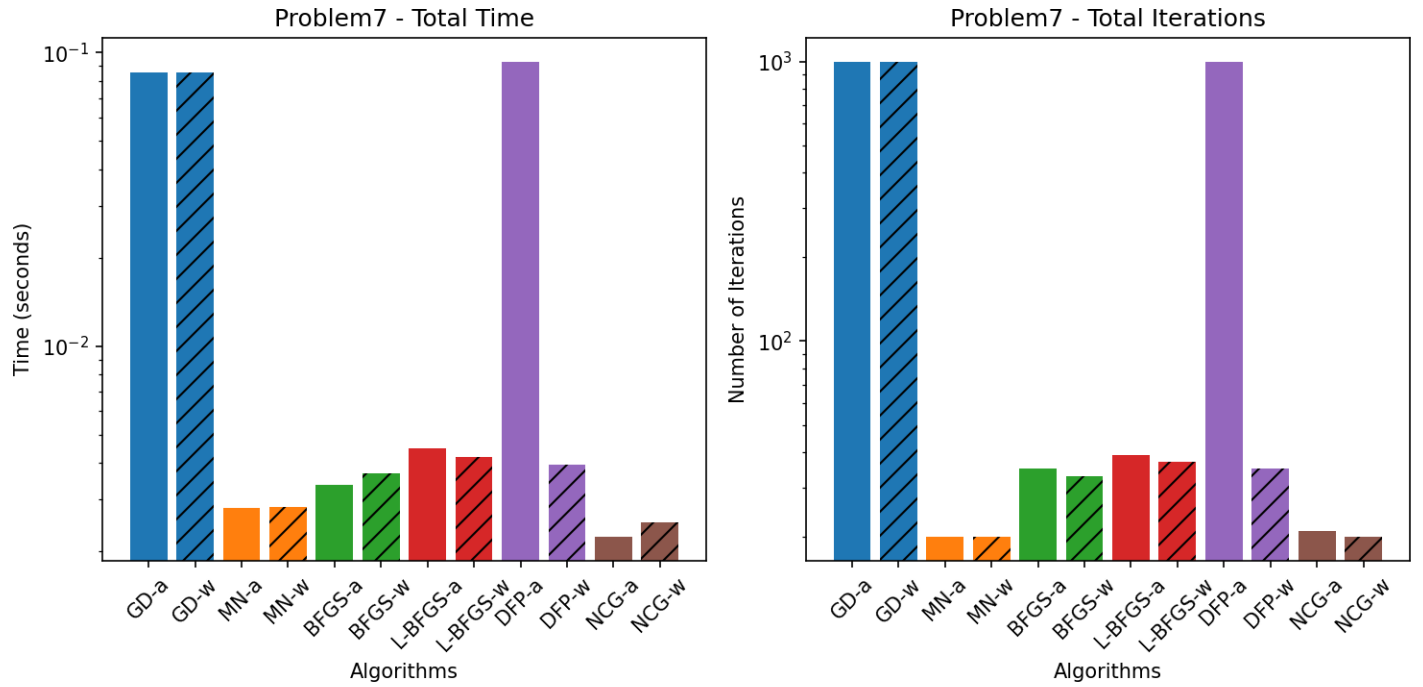


Problem7 - Function Value (All Iterations)



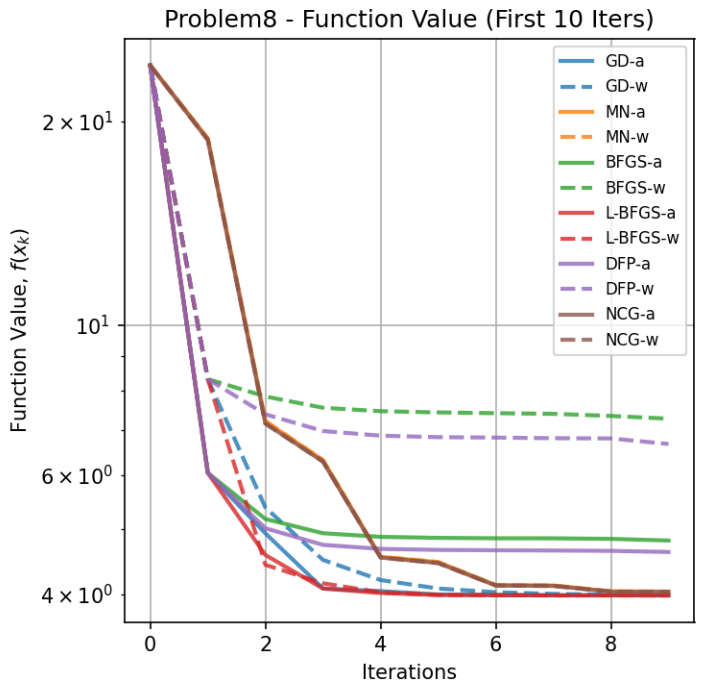
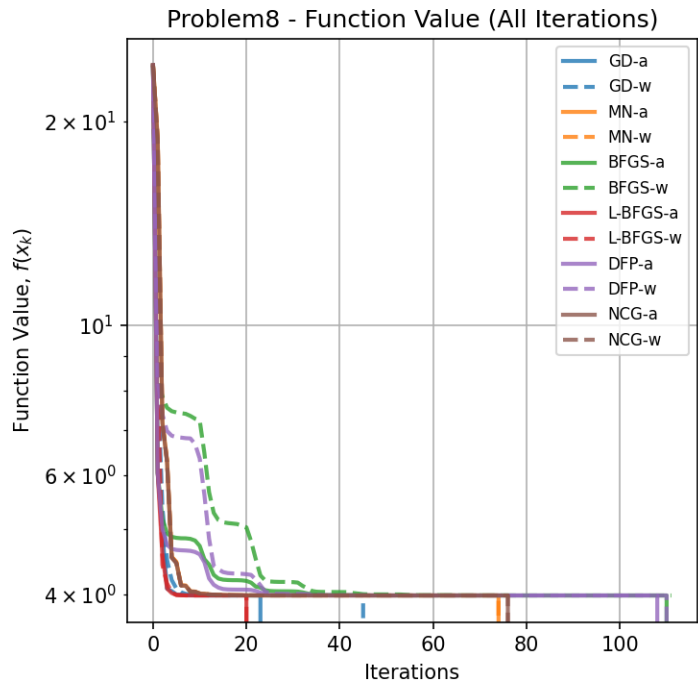
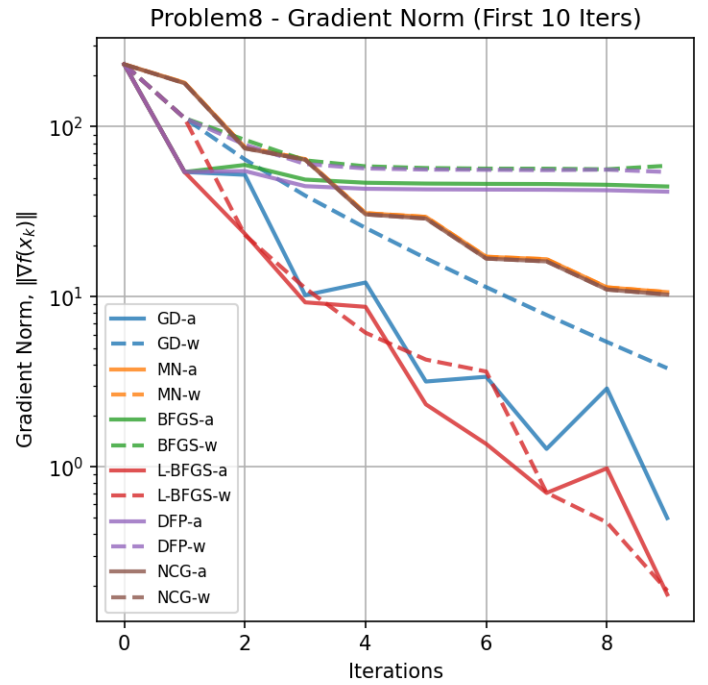
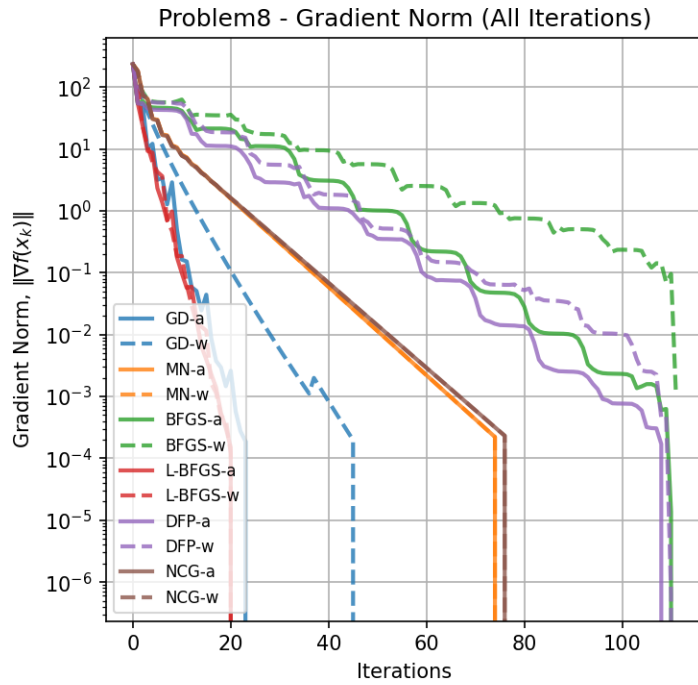
Problem7 - Function Value (First 39 Iters)



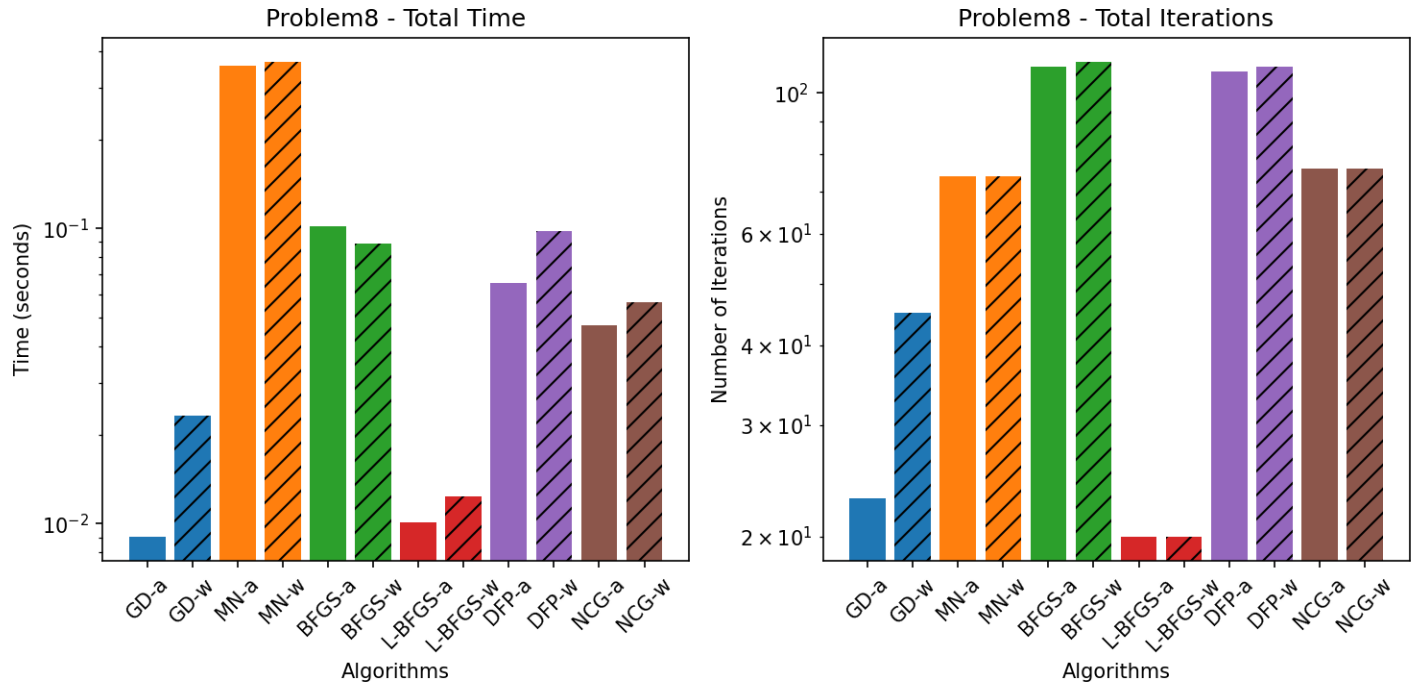


### Problem 8

	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	23	0.00904632	Converged. Gradient norm is below tolerance.	218	47	0
GD-w	45	0.0232189	Converged. Gradient norm is below tolerance.	540	46	0
MN-a	74	0.356224	Converged. Gradient norm is below tolerance.	149	150	75
MN-w	74	0.368056	Converged. Gradient norm is below tolerance.	149	76	75
BFGS-a	110	0.102041	Converged. Gradient norm is below tolerance.	924	332	0
BFGS-w	112	0.0890164	Converged. Gradient norm is below tolerance.	1124	226	0
L-BFGS-a	20	0.0100827	Converged. Gradient norm is below tolerance.	50	61	0
L-BFGS-w	20	0.0123529	Converged. Gradient norm is below tolerance.	53	41	0
DFP-a	108	0.0655756	Converged. Gradient norm is below tolerance.	623	326	0
DFP-w	110	0.0982966	Converged. Gradient norm is below tolerance.	730	222	0
NCG-a	76	0.0471478	Converged. Gradient norm is below tolerance.	153	154	77
NCG-w	76	0.0563343	Converged. Gradient norm is below tolerance.	153	78	77

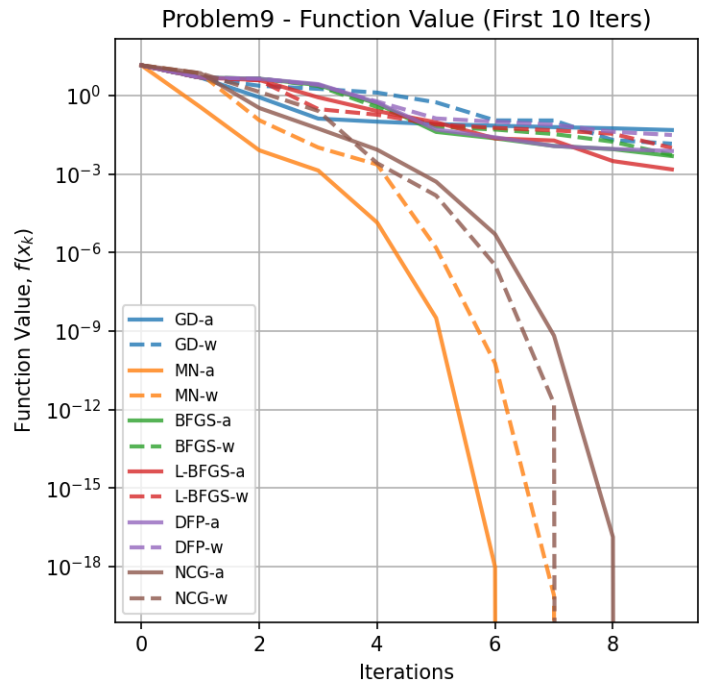
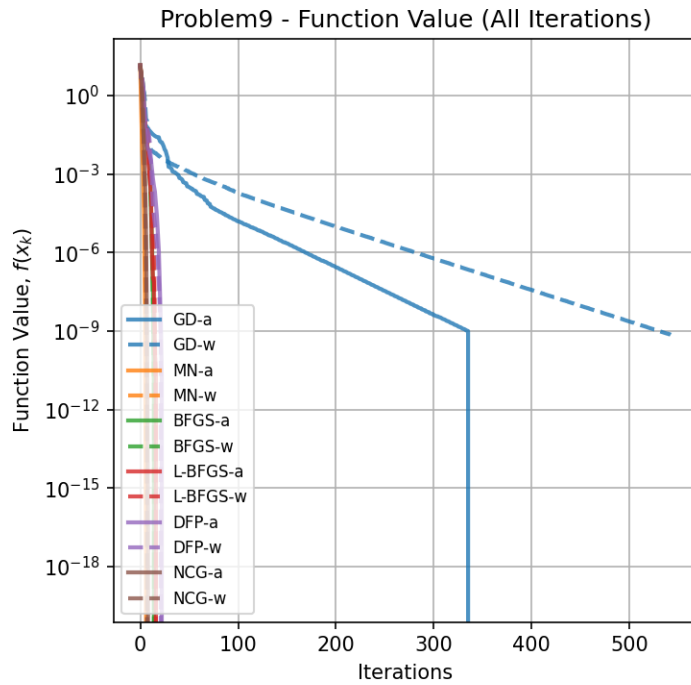
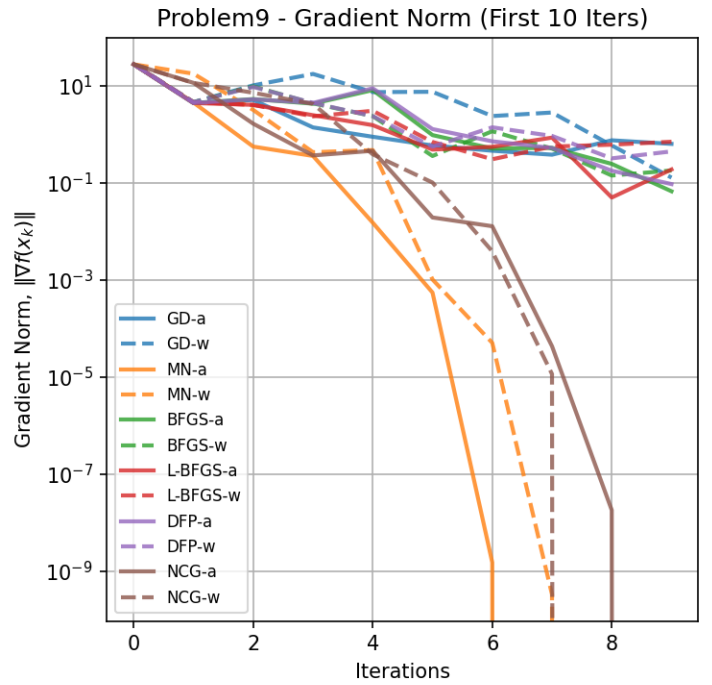
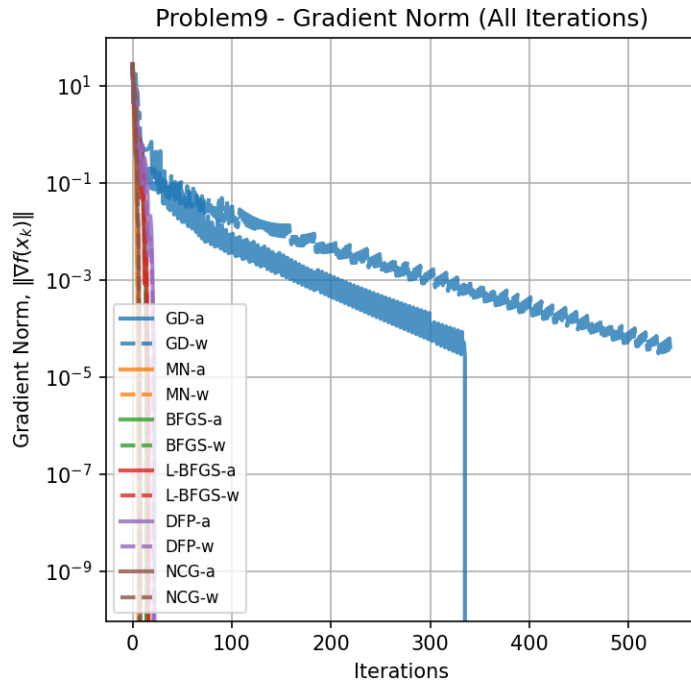


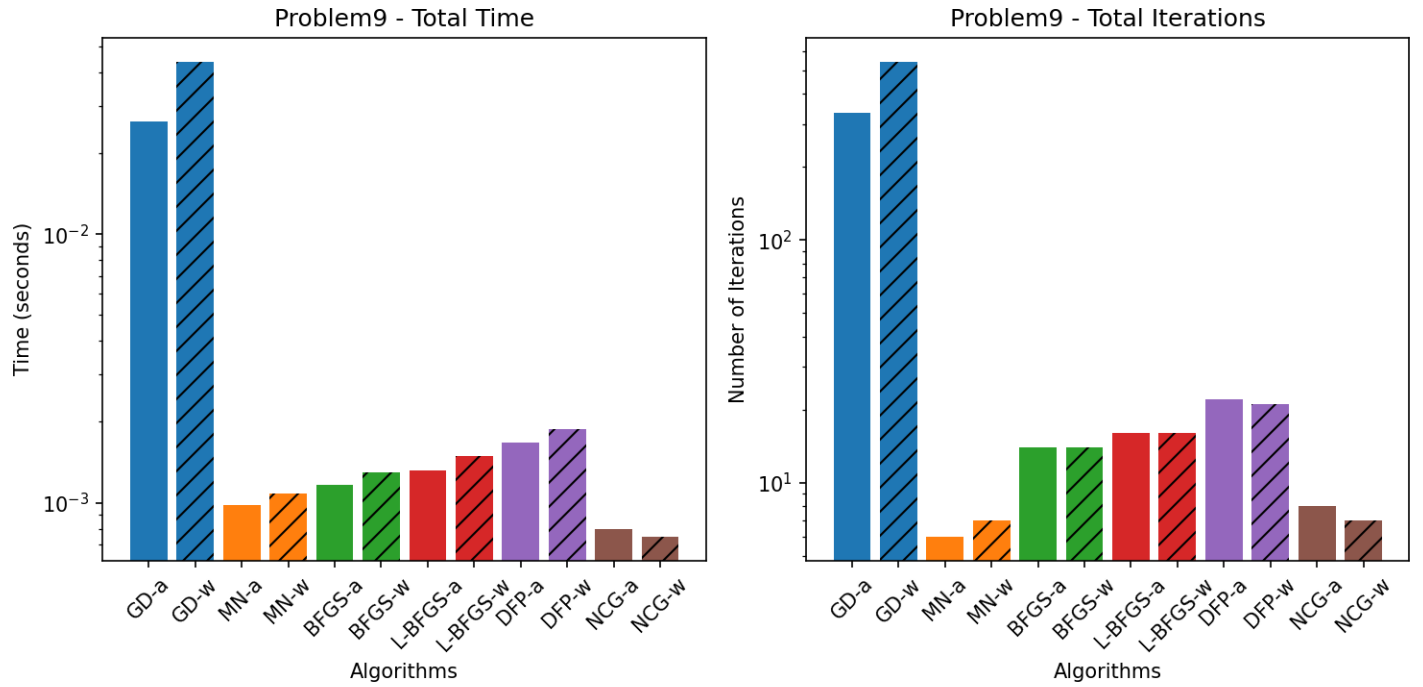




### Problem 9

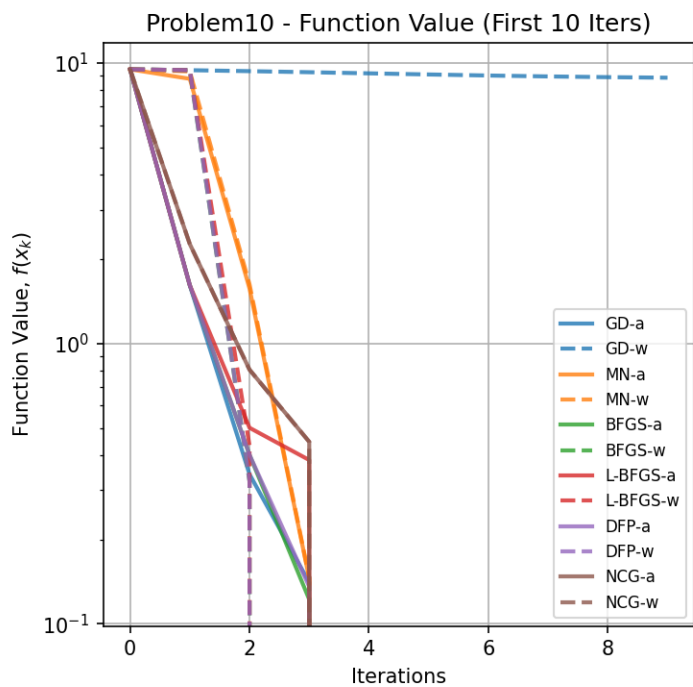
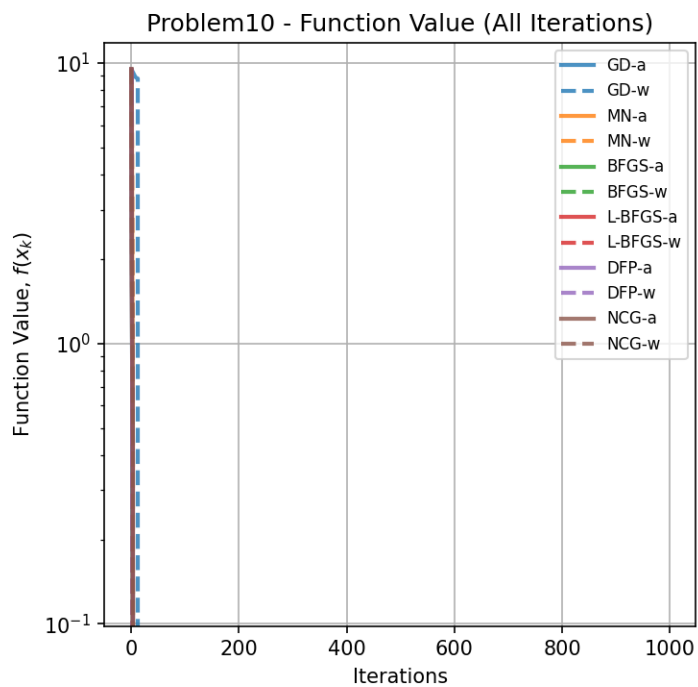
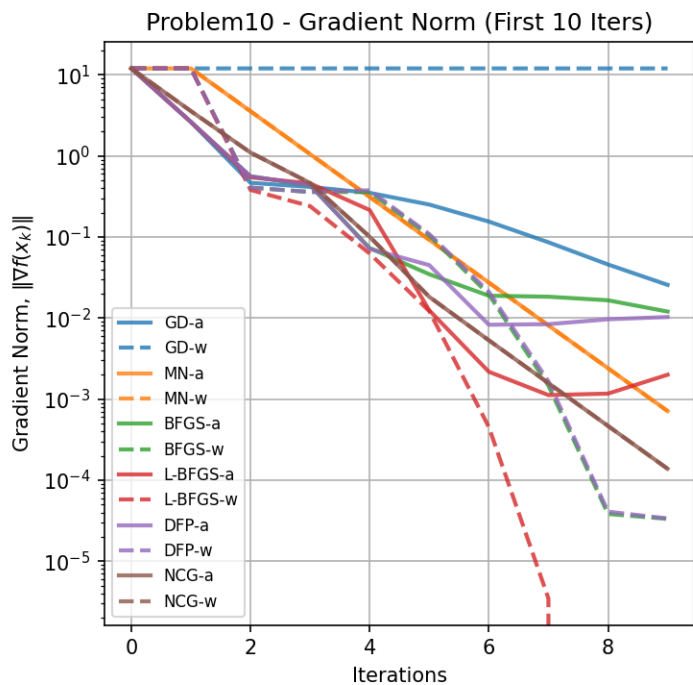
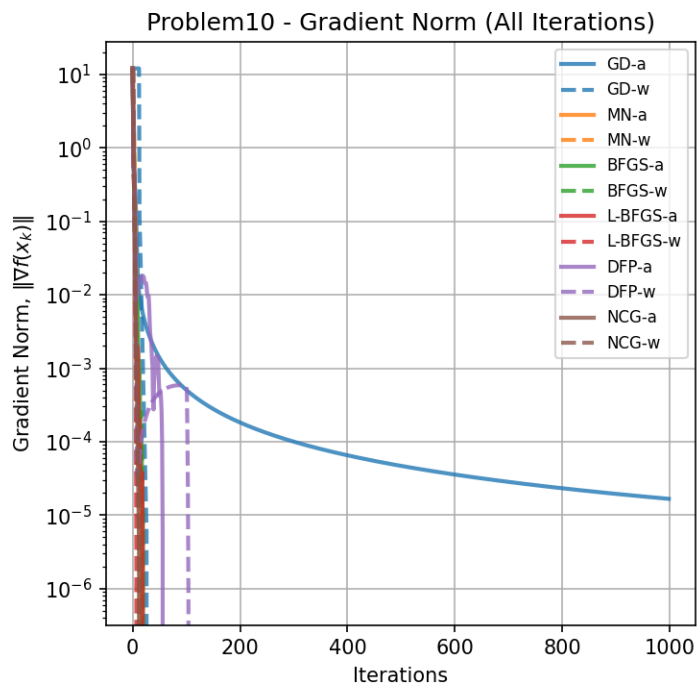
	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	335	0.0262542	Converged. Gradient norm is below tolerance.	1740	671	0
GD-w	543	0.0440662	Converged. Gradient norm is below tolerance.	3523	544	0
MN-a	6	0.000978947	Converged. Gradient norm is below tolerance.	25	14	7
MN-w	7	0.00108075	Converged. Gradient norm is below tolerance.	55	9	8
BFGS-a	14	0.00116396	Converged. Gradient norm is below tolerance.	36	44	0
BFGS-w	14	0.00129557	Converged. Gradient norm is below tolerance.	37	30	0
L-BFGS-a	16	0.00131512	Converged. Gradient norm is below tolerance.	39	49	0
L-BFGS-w	16	0.00149012	Converged. Gradient norm is below tolerance.	44	33	0
DFP-a	22	0.00167918	Converged. Gradient norm is below tolerance.	52	68	0
DFP-w	21	0.00187778	Converged. Gradient norm is below tolerance.	51	44	0
NCG-a	8	0.000794649	Converged. Gradient norm is below tolerance.	19	18	9
NCG-w	7	0.000747204	Converged. Gradient norm is below tolerance.	17	9	8

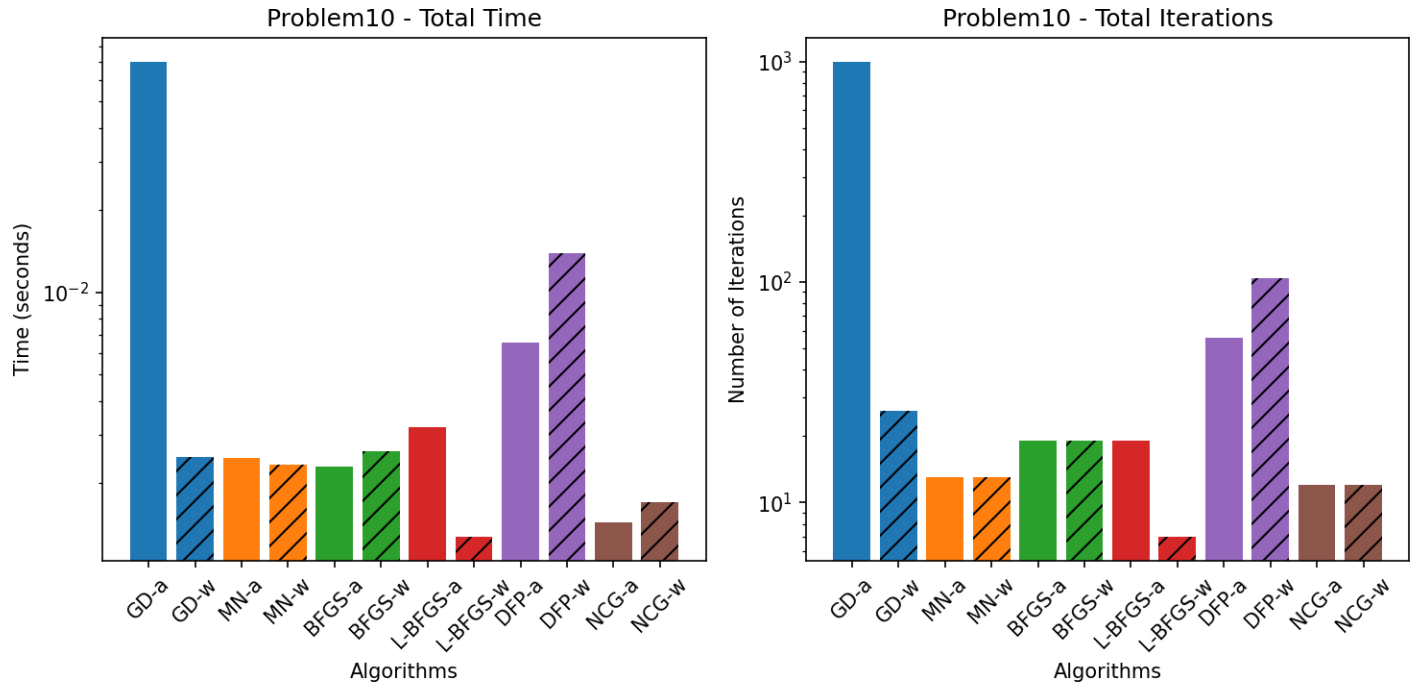




### Problem 10

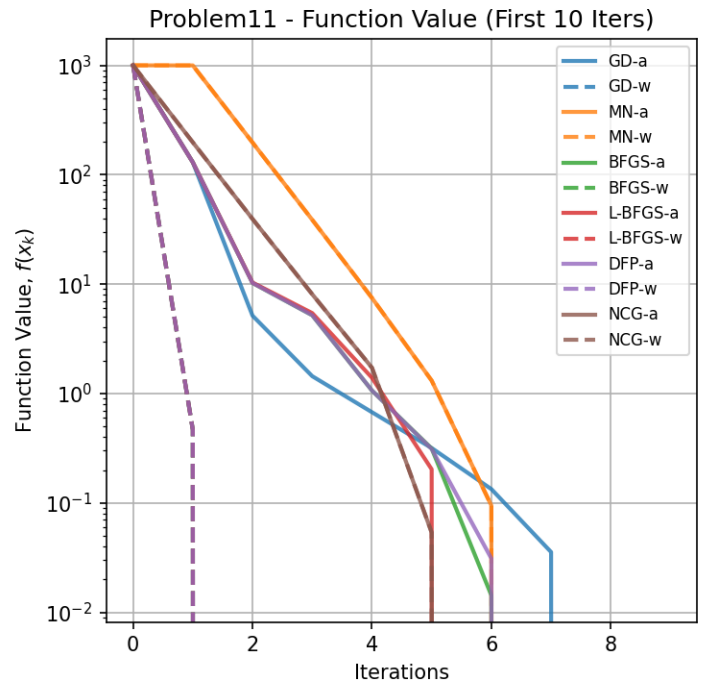
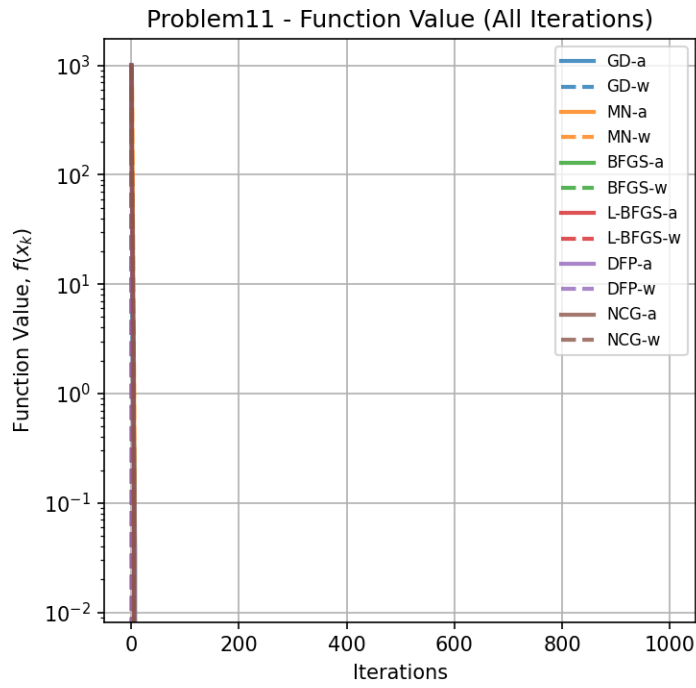
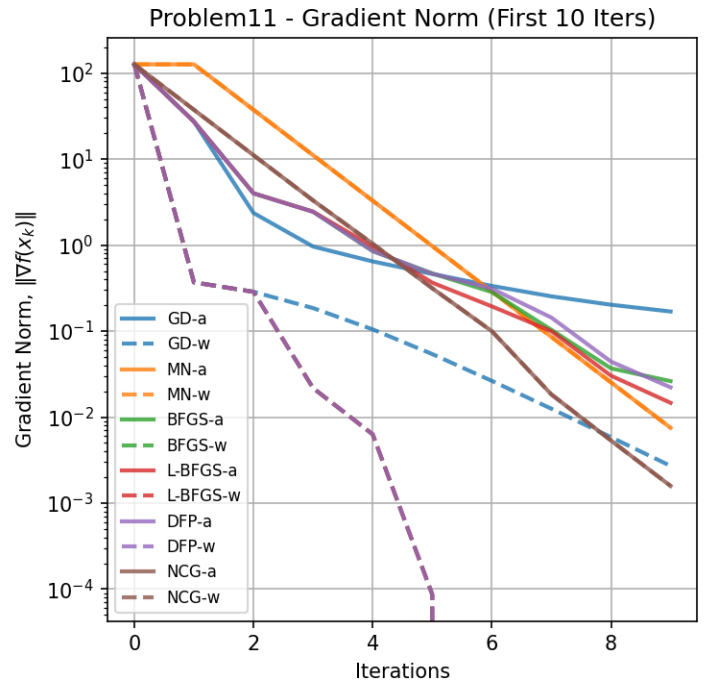
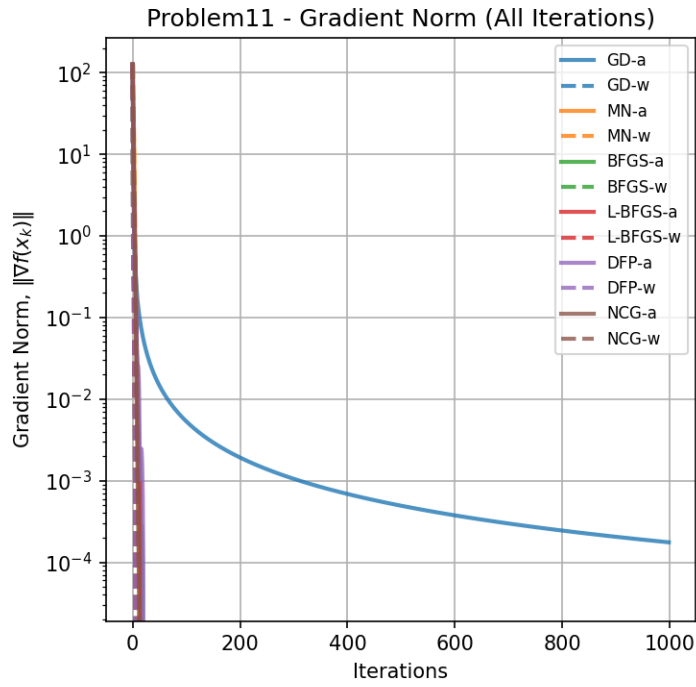
	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	999	0.0701935	Failed. Maximum iterations reached.	2001	2000	0
GD-w	26	0.0024941	Converged. Gradient norm is below tolerance.	67	27	0
MN-a	13	0.00245905	Converged. Gradient norm is below tolerance.	35	28	14
MN-w	13	0.00232315	Converged. Gradient norm is below tolerance.	37	15	14
BFGS-a	19	0.00230002	Converged. Gradient norm is below tolerance.	41	59	0
BFGS-w	19	0.00261617	Converged. Gradient norm is below tolerance.	42	41	0
L-BFGS-a	19	0.00319028	Converged. Gradient norm is below tolerance.	42	58	0
L-BFGS-w	7	0.00127006	Converged. Gradient norm is below tolerance.	18	19	0
DFP-a	56	0.00652218	Converged. Gradient norm is below tolerance.	118	170	0
DFP-w	104	0.0139029	Converged. Gradient norm is below tolerance.	215	222	0
NCG-a	12	0.00142813	Converged. Gradient norm is below tolerance.	25	26	13
NCG-w	12	0.00169826	Converged. Gradient norm is below tolerance.	25	14	13

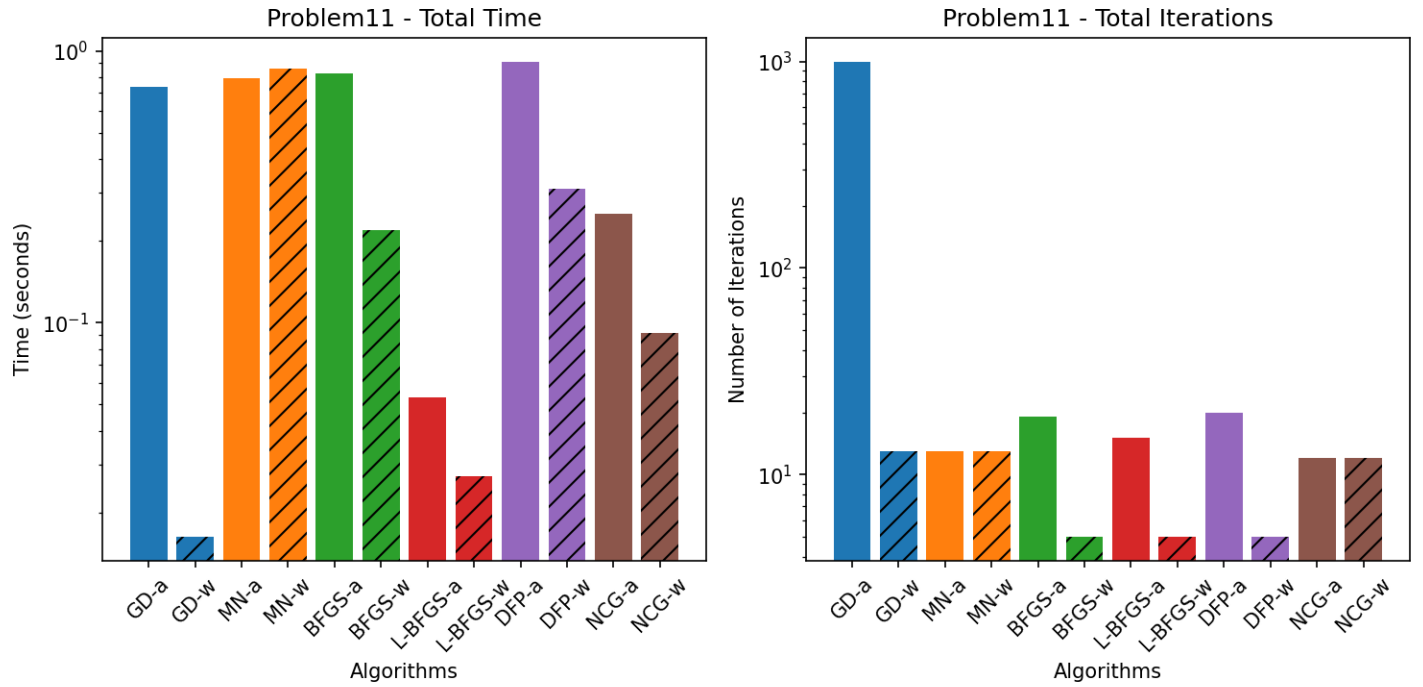




### Problem 11

	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	999	0.735502	Failed. Maximum iterations reached.	2001	2000	0
GD-w	13	0.0163422	Converged. Gradient norm is below tolerance.	29	16	0
MN-a	13	0.794621	Converged. Gradient norm is below tolerance.	35	28	14
MN-w	13	0.862959	Converged. Gradient norm is below tolerance.	37	15	14
BFGS-a	19	0.823527	Converged. Gradient norm is below tolerance.	40	59	0
BFGS-w	5	0.218202	Converged. Gradient norm is below tolerance.	16	14	0
L-BFGS-a	15	0.0533395	Converged. Gradient norm is below tolerance.	32	46	0
L-BFGS-w	5	0.0271885	Converged. Gradient norm is below tolerance.	16	15	0
DFP-a	20	0.91292	Converged. Gradient norm is below tolerance.	42	62	0
DFP-w	5	0.310616	Converged. Gradient norm is below tolerance.	16	14	0
NCG-a	12	0.252544	Converged. Gradient norm is below tolerance.	25	26	13
NCG-w	12	0.0918741	Converged. Gradient norm is below tolerance.	25	14	13





## Problem 12

	Iters	Time	Convergence	Func Evals	Grad Evals	Hess Evals
GD-a	146	0.0233016	Converged. Gradient norm is below tolerance.	352	293	0
GD-w	209	0.0470793	Converged. Gradient norm is below tolerance.	674	223	0
MN-a	69	0.0307856	Converged. Gradient norm is below tolerance.	613	140	70
MN-w	82	0.0424604	Converged. Gradient norm is below tolerance.	920	88	83
BFGS-a	72	0.0176868	Converged. Gradient norm is below tolerance.	179	218	0
BFGS-w	47	0.0138445	Converged. Gradient norm is below tolerance.	111	98	0
L-BFGS-a	26	0.00723386	Converged. Gradient norm is below tolerance.	64	79	0
L-BFGS-w	27	0.00877953	Converged. Gradient norm is below tolerance.	65	55	0
DFP-a	999	0.245044	Failed. Maximum iterations reached.	2025	3001	0
DFP-w	999	0.283537	Failed. Maximum iterations reached.	2029	2066	0
NCG-a	55	0.0145164	Converged. Gradient norm is below tolerance.	122	112	56
NCG-w	30	0.0100608	Converged. Gradient norm is below tolerance.	66	42	31

